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MARISSA MAYER TAKES ON THE WORLD

LOCATION SERVICES ARE WHERE IT'S AT—AND SHE'S THE BOSS

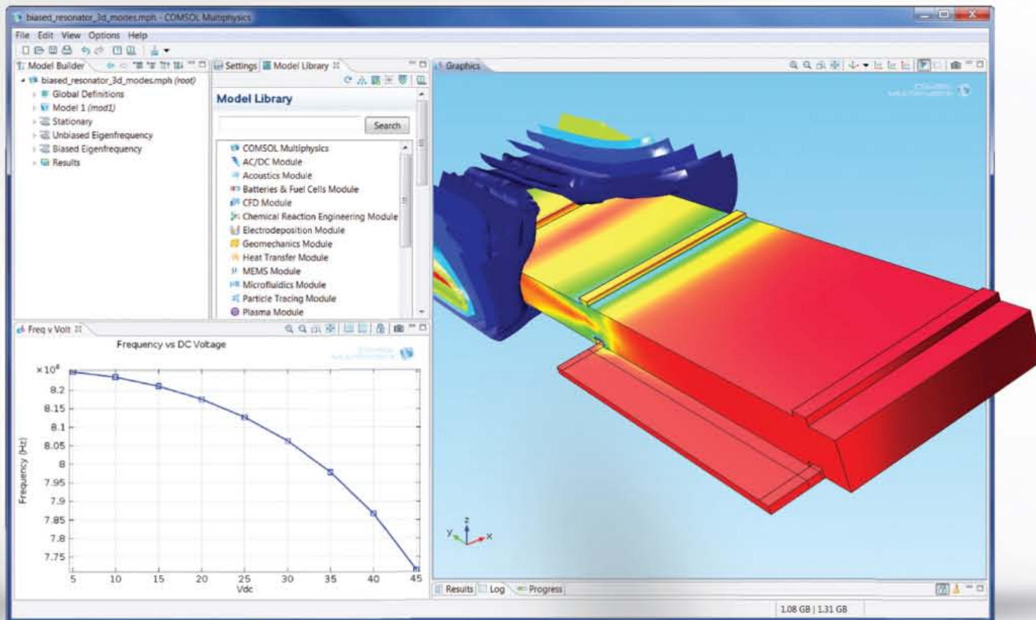
DEFLECTING ASTEROIDS

THE RELAY REBORN

TOP 10 TECH CARS

IEEE

MEMS DEVICES: An electrostatically actuated MEMS resonator is simulated showing the electric potential and deformation. The resonant frequency changes with DC bias.



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Though electric drive is now a fixture in our annual list of technically interesting automotive developments, this year the internal combustion engine is striking back. *By Lawrence Ulrich*

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In any given decade, the chances are slim that a mountain-size rock will collide with Earth, but if one ever does, it will ruin your whole day. Now is the time to prepare countermeasures based on solar sails, a technology that can also find application in the exploration of space. *By Gregory L. Matloff*

COVER: GABRIELA HASBUN; THIS PAGE, TOP: MCLAREN AUTOMOTIVE; BOTTOM: GABRIELA HASBUN

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Latest Project
Building a robotic tuna to swim across the Atlantic Ocean
NI LabVIEW
LabVIEW makes me better by making complex
CONTROL
simple and accessible

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Spectrum Goes App

This is the year we plant our flag firmly in the smartphone and tablet realms. First up: an app for our award-winning weekly podcast series, "Techwise Conversations," hosted by Senior Associate Editor Steven Cherry. It's available now from the Amazon app store and from Apple via the Wizzard Media app. For details, go to http://spectrum.ieee.org/twcapp.

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KEEPING LAPTOPS ALIVE IN HAITI
When a primary school in Lascahobas, Haiti, received 400 laptops from the nation's ministry of education, one important factor was overlooked: how to keep the batteries charged. With funding from the IEEE Foundation, a group that included IEEE Member Laura Hosman and her students built a solar-powered charging station for the school.

HISTORY CENTER GETS BUSY PUBLISHING
As part of its mission to bring the history of technology to a wider audience, the IEEE History Center has been busy with a number of initiatives. The center recently published *Bell Labs Memoirs: Voices of Innovation* and *The U.S. Federal Government and Innovation: A Brief History*, among other publications.

IEEE TECHNOLOGY NAVIGATOR ADDS NEW FEATURES
The online tool for browsing through IEEE's vast collection of technical resources now has a more user-friendly interface, making it easier to find information and adding more ways to find the content you're seeking.

LEFT: THOMAS FULLER/INTERNATIONAL HERALD TRIBUNE; RIGHT: LAURA HOSMAN

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back story

The Car Made of Unobtainium

LAWRENCE ULRICH

IF YOU want to test-drive an SUV under winter conditions, any empty, snow-filled parking lot will do. But Ferrari, being Ferrari, wanted to make more of a statement. So to show off its first-ever SUV, the Italian supercar maker put our own Lawrence Ulrich [right] and a band of colleagues into a cable car and ran them up the Plan de Corones, a mountain in the Dolomites, in the South Tyrol.

There, waiting for the journalists, were six Ferrari FFs—sleek, red, and menacing. Each one had been airlifted individually by Chinook helicopter. "The mountains were actually pink, especially when the sun hit them right," Ulrich says. "Everything looked like *The Sound of Music*." Except for the racecourse carved into the wintry wonderland.

"They had dug out a snow course wide enough for a car, with maybe a dozen curves," Ulrich says. "First we rode shotgun, alongside Ferrari's driver, Raffaele De Simone. Then we each got to jump in and test a car ourselves."

There's no denying the thrill of slaloming US $300 000 worth of superexotic Italian apparatus through the legendary highlands that gave the world yodeling, funny shoes, and odd leather breeches. But such cars are more than just aphrodisiacs for the middle-aged and paunchy, because they often showcase technologies that will show up in production cars in another decade or so.

Of course, some things—like the gas-guzzling 485-kilowatt V-12 engine—may never reach the shopping mall. "You have to remember, these fantasy cars are made mostly of unobtainium," Ulrich says. "A $30 000 car that does what it's designed to do can in fact be more impressive."

Just how unobtainable the car is struck Ulrich after he took the FF on the Autostrada, got it up to around 270 kilometers per hour (170 miles per hour), and turned into a truck stop to fill its 90-liter tank. The bill came to $160—a personal best (or worst). "The attendant was amused at the look on my face," Ulrich says. ❑

CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, The Data is in *IEEE Spectrum,* Vol. 49, no. 4 (INT), April 2012, p. 60, or in *IEEE Spectrum*, Vol. 49, no. 4 (NA), April 2012, p. 72.

contributors

TOM BURKE wanted to upgrade his soldering iron, but US $500 was too much to spend. So he got a $50 toaster oven from Walmart and, as he describes in this issue, turned it into "The Poor Man's Solder Reflow Oven" [p. 20]. Burke is a senior systems engineer at Oceaneering, in Hanover, Md. He has a B.S.E.E. and M.S.E.E. from Southern Illinois University and a master's of software engineering from Johns Hopkins University.

YU-TZU CHIU is a Taipei correspondent for Bloomberg BNA. "Taiwan's Tech Hubs Take Advantage of Disasters" [p. 9] is her second story about the effects of last year's earthquake and tsunami on the global supply chain. She has chronicled Taiwan's tech policies for *IEEE Spectrum* since 2000.

RITCHIE S. KING, who analyzed the boom in the liquefied natural gas market for The Data [p. 60], formerly dealt with numbers full-time as a chemical process engineer. Unlike most engineers, though, he enjoyed writing reports and making charts more than any other aspect of the job. In 2009, King decided to make writing about science and technology a full-time gig. He landed an internship at *Spectrum* last year and is currently a freelance journalist based in Brooklyn.

TSU-JAE KING LIU, DEJAN MARKOVIĆ, VLADIMIR STOJANOVIĆ, and **ELAD ALON** pursue a blast from the past in "The Relay Reborn" [p. 32]. IEEE Fellow Liu, a professor of electrical engineering and computer sciences at the University of California, Berkeley, suspected that miniature mechanical switches could be an attractive, low-power alternative to silicon transistors, but she needed circuit designers to help prove it. Marković, an electrical engineering professor at the University of California, Los Angeles; Stojanović, a professor at MIT; and Alon, a fellow Berkeley professor, all eagerly joined the effort.

ALEXANDER B. MAGOUN, an outreach historian at the IEEE History Center in New Brunswick, N.J., highlights the radio reforms accelerated by the sinking of the *Titanic* in April 1912 [p. 16]. Formerly head of the David Sarnoff Library, he believes that Sarnoff would have gone on to greater things even if he hadn't relayed messages during the disaster. Magoun's own maritime distress experience, he says, "extends no farther than a becalmed Dyer Dhow off Tuck's Point in Manchester, Mass."

GREGORY L. MATLOFF, an emeritus associate professor of physics at New York City College of Technology, is a pioneer of what might well be termed celestial engineering. In "Deflecting Asteroids" [p. 50], he discusses using solar sails to manipulate the rocks and ice balls that orbit the sun and occasionally collide with our planet. He has consulted with NASA on this idea, as well as on using sails for deep-space propulsion. He is a coauthor of *Solar Sails: A Novel Approach to Interplanetary Travel* (Springer, 2008).

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The World According to DARPA

REGINA DUGAN: The first female director of DARPA pushed the agency to bet on technologies that benefit society as well as the U.S. military.

THE MOST famous name in American innovation today isn't Apple or Google. Nor is it Facebook, Boeing, or Intel.

The iconic American innovator is a government agency that neither earns a profit nor sells a single consumer product. That DARPA, the Defense Advanced Research Projects Agency, runs with the big dogs of commercial innovation reflects the importance of science and technology to national security. War, not necessity, is the mother of invention.

But there's also a deeper lesson: Less can be more. The Pentagon spends more than US $75 billion on R&D annually; DARPA's share is less than $3 billion. By comparison, Ford and GM each spend more on R&D than DARPA. So do Intel, Microsoft, and Cisco. Merck does too.

Since its inception as the Advanced Research Projects Agency in the late 1950s, the agency has gotten a lot of bang for its buck by placing shrewd bets on a variety of high-potential areas. None paid off bigger than the ARPANET, a communications architecture originally conceived to protect U.S. networks against a Soviet strike. Eventually, that network led to the Internet. The agency, later renamed to underscore its military orientation, became legendary.

During the past decade, DARPA lost its mojo. In the mid-2000s, at the height of the Iraq and Afghan wars, the agency accepted too many combat tasks, which consumed its attention and resources. I recall listening to Anthony Tether, DARPA's director at the time, complain about the difficulties of inventing technologies to thwart roadside bombs in Iraq and Afghanistan. Dozens of solutions were tried; all failed after the attackers made adjustments.

Distracted by the immediate, DARPA found itself unable to spend hundreds of millions of budgeted dollars. Contracts took longer to ink, there were fewer bold projects, and grants to universities fell by half.

Three years ago, DARPA began a welcome return to its roots under the leadership of Regina Dugan, who became the first female director of the agency in July 2009. Dugan immediately sought to award grants more quickly and pursue "moon shots" with high-potential payoffs for the entire nation, not just the "mini-society," as she called it, of the military.

Some examples of DARPA's new goals that have "cascading" benefits include technologies that would enable us to fly anywhere on the planet in a single hour, grow vaccines in plants to protect against pandemics, and build a robot that runs faster than a cheetah.

To be sure, Dugan's legacy will not be known for some years, but she put her stamp on an agency that few even realized had gone dangerously off course. The secret to her early success, as she stated, amounted to this:

COOL FACTOR: Part of DARPA's new push is to leverage "democratized, crowd-sourced innovation," as Dugan told the U.S. Congress two years ago. To ignite interest, DARPA rolls out a stream of contests open to virtually everyone. These popular contests create buzz for the agency, which in turn attracts talent. The agency relies on a mere 120 program officers, who rotate through on three-year terms. That creates a constant pressure to replenish what Dugan called "the DARPA army of technogeeks."

TEST: In a departure from DARPA history, Dugan said the Pentagon ought to move from a "buy then make" practice, which leads to cost overruns and faulty systems galore, to a "make then buy" approach, which allows manufacturing scale to occur after a system has proved its mettle.

TARGET: Dugan seemed more aware than her predecessors of the crucial importance of choosing the right targets—where the benefits are wide and progress is possible. In the case of hypersonic flight, she set a speed target of Mach 20 (20 times the speed of sound). Recently, the agency reported that an unmanned "boost-glide maneuvering vehicle," achieved "fully aerodynamically controlled flight at Mach 20" for a period of 3 minutes before it was lost. As Kaigham J. Gabriel, then DARPA's deputy director, testified to Congress in February, "There's no way to learn to fly at Mach 20 unless you build...and fly."

DARPA clearly isn't infallible. While competing nations concentrate their best and brightest on commercial innovations, DARPA could become a symbol of how American ingenuity lost its way. Or even worse, DARPA could become so successful that the private sector devours its best brains.

Which may explain why Dugan was hired by Google in March.

—G. Pascal Zachary

G. Pascal Zachary is a professor of practice at the Consortium for Science, Policy and Outcomes at Arizona State University and a frequent contributor to IEEE Spectrum.

update

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Taiwan's Tech Hubs Take Advantage of Disasters

After Japan's earthquake and Thailand's floods, firms are building backup manufacturing sites

APART FROM causing human tragedy, the Japanese earthquake and tsunami on 11 March 2011 and the floods in Thailand later that year were a test of the global technology supply chain. That supply chain turned out to be vulnerable to local events, which in turn has made having backup manufacturing infrastructure much more valuable. Now Taiwan is positioning itself to become a major backup production base for Japanese firms involved in the electronics supply chain.

In 2011, the Taiwanese government assisted 25 investment deals involving Japanese firms valued at NT$107.9 billion (US $3.66 billion), and the government projects many more in 2012. It's quite a turnaround. Japan accounted for one-third of foreign direct investment in Taiwan in the 1980s, but its investments dropped to 11 percent over the past decade.

HIGH WATERS: Thailand became a weak spot in the electronics supply chain when the flooding of local hard-drive makers affected the earnings of chipmakers and computer manufacturers.

PHOTO: THOMAS FULLER/ INTERNATIONAL HERALD TRIBUNE/REDUX

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2600 PERCENT Increase in the demand for dysprosium, a rare earth element, over the next 25 years due to the boom in wind turbines and electric vehicles.

update

Superconducting Wind Turbines

As part of its search for alternatives to rare earth elements in short supply, the U.S. Advanced Research Projects Agency for Energy is putting more than US $30 million into superconducting wind turbine research. The superconductors, like those from SuperPower of Schenectady, N.Y., would replace heavy, permanent magnets in turbines that now rely on rare earth materials. The resulting systems would be so light that they'd lead to turbines with nearly double the power of today's.

"We predict that the trend will continue to grow in the following two to three years, because the reconstruction in Japan takes time," says Wen-ke Yang, director-general of the Central Taiwan Science Park Administration.

Officials attribute the new investment not only to the challenging investment environment in Japan—which involves a lengthy construction process and the appreciation of the Japanese yen—but also having access to China. In 2010 China and Taiwan signed the Economic Cooperation Framework Agreement (ECFA), which offers preferential tariffs or easier market access to goods traded across the Taiwan Strait.

The island nation, which hasn't had diplomatic relations with Japan since 1972, is going all out to bring in Japanese firms. In September 2011, Taiwan inked a deal that makes it possible for companies to enjoy the same benefits as domestic firms when investing in each other's territories. And it streamlined the process of getting government help with Japanese investment in March.

More concretely, in February, Taiwan set aside a special 73.6-hectare zone, called the Taiwan-Japan Park (TJ Park), enough for dozens of manufacturers, according to Wei-cheng Lin, deputy director-general of the administration bureau of the Southern Taiwan Science Park. Lin says his science park now hosts 18 Japanese firms out of a total of 43 in Taiwan's three science parks and is reviewing applications from 5 more.

TJ Park is part of a bigger five-year plan to establish more ties between Taiwanese and Japanese firms. Other strategies include a venture fund, loans, and incentives for joint R&D projects.

The Japanese newcomers include makers of equipment and materials used in semiconductor manufacturing. For example, Hitachi Chemical Co., which makes chemicals for silicon wafer polishing, plans to invest 2 billion yen (NT$730 million and US $25 million) at TJ Park to build its first overseas production line.

Hitachi will be joining many others, such as glassmaker Ohara Optical Co., which plans to invest NT$400 million (US $13.57 million) in a site at Central Taiwan Science Park and shift 30 percent of its glass-melting production there in 2013.

Ohara also expects the Taiwan subsidiary to have better access to rare earth metals from China than production bases in Japan do. Japanese firms have had to reduce rare earth consumption, thanks to China's export controls. So the company's investment points to reasons other than disaster-proofing its supply chain for a new plant in Taiwan. —Yu-Tzu Chiu

SUPERPOWER

Six Paths to Longer Battery Life

These six technologies could save on smartphone power

THE BOOM in mobile devices and data servers has circuit designers racing to find new ways to slash power consumption. At this year's International Solid-State Circuits Conference, in San Francisco, six power-saving technologies took center stage. Some will emerge in products this year, while others are just beginning to catch the interest of major chipmakers.

NEAR-THRESHOLD COMPUTING

Academics have long toyed with the idea of operating chips at a point very close to the threshold voltage—the amount needed to switch a transistor on. Now the scheme seems to be getting picked up by industry. Intel researchers discussed a 32-nanometer, Pentium-class chip they've built that can operate from 1.2 volts—de rigueur for today's processors—all the way down to 280 millivolts. The chip's sweet spot for energy efficiency was 450 mV, just above the threshold voltage. At that level, Intel's chip ran slowly, at less than 100 megahertz, but it also consumed just about a fifth of the energy it did at 1.2 V. Parallel processing could be used to pick up some of the slack in performance.

RAZOR-THIN MARGINS

Engineers typically run chips at a higher voltage than needed in order to prevent clocking errors. If chips had a way to detect errors and change their operating voltage on the fly, engineers could push chips to operate at the lowest voltage possible, saving power in the process. The scheme, called Razor, is still largely stuck in academic circles. But researchers from the University of Michigan, in Ann Arbor, and Harvey Mudd College, in Claremont, Calif., showed that the approach works on an ARM Cortex-M3 processor, boosting energy efficiency by 60 percent. The team says it's the first implementation of a Razor-style scheme on a complete commercial processor.

SMALLER TRANSISTORS

Intel has packed 1.4 billion 3-D transistors onto Ivy Bridge, its next-generation processor. The switch to less leaky 3-D transistors has given the new chip a big power boost. The 22-nm Ivy Bridge chips can be run just as fast as the company's previous chips, but with an operating voltage that's 200 mV lower. Intel has also incorporated designs at the circuit and core level to improve the chip's power management. A separate system-on-a-chip code-named Silvermont, based on the same transistor-making process, will be geared for mobile handsets.

ALL-DIGITAL PHASE LOCKING

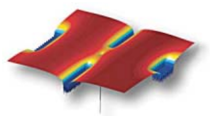
Phase-locked loops—which lock in and track an input signal—are vital circuit elements that are used to sync modern processors to their clocks and pick up and transmit radio signals. In the past, these circuits were built with analog components, but all-digital variants consume a tenth of the power and are easier to fabricate. Mobile powerhouse Samsung presented a new improvement on the all-digital phase-locked loop, a 0.012-square-millimeter circuit that consumes just 2.5 mW. Intel showed off a version of the circuit, built with the company's 22-nm technology, that consumes as little as 0.7 mW.

SMART CONVERTERS

Another basic circuit headed for a low-power makeover is the switched capacitor, which is often used to convert analog signals to digital. A team at Oregon State University, in Corvallis, debuted a low-power component that was inspired by the ring oscillator, a common test circuit made of a loop of inverters. Another team at the National Chiao Tung University, in Hsinchu, Taiwan, found a way to save power by working on signals in two separate stages—one for crude processing and the other for fine-tuning—that can each be optimized.

NEXT-GENERATION DYNAMIC RAM

Memory makers Samsung and Hynix Semiconductor both unveiled details on the next incarnation of synchronous DRAM, the memory that drives today's processors. The new generation, which goes by the name DDR4, boasts circuit tricks that let Samsung drop the supply voltage to its memory modules from 1.5 V to 1.2 V. The modules also include better clocking and faster algorithms for encoding data to be sent to and fetched from memory. DDR4 may make its commercial debut as early as 2013. —*Rachel Courtland*



news brief

A Single-Atom Transistor

Researchers in Australia, South Korea, and the United States have created a working transistor out of a single phosphorus atom embedded in silicon. They used a scanning tunneling microscope and a technique common in lithography to replace one silicon atom in a six-atom lattice with a phosphorus atom. When they applied a voltage across the phosphorus atom, it behaved like a transistor, switching and amplifying an electric current.

LEFT: ISTOCKPHOTO; RIGHT: PURDUE UNIVERSITY

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update

WOOD FIRED: North American wood is fueling Europe's biomass and coal plants.
PHOTO: RWE

Europe Looks to North America's Forests to Meet Renewable Energy Goals

Emissions reductions, however, may prove smaller and slower than once expected

An ENERGY export boom is sweeping U.S. forests. The trees are fast becoming a crucial energy supply for European power producers seeking to meet the European Union's goal for renewable energy use and carbon emissions reductions. Blending in biomass to coal-fired power stations is an increasingly popular strategy to meet the European targets, which call for renewable sources to meet 20 percent of energy demand by 2020 and for a 20 percent cut in greenhouse gas emissions from 1990 levels.

Experts in life-cycle analysis, however, question whether burning biomass to generate power does Earth's atmosphere much good. That's because trees harvested expressly for power generation—which European Commission–financed research predicts will account for three-fifths of utilities' biomass supply needs through 2020—potentially could have grown larger and absorbed more carbon from the atmosphere if they had been left unharvested.

Regulators appear to be listening. Late last year, the Commission's European Environment Agency and the U.S. Environmental Protection Agency concluded independently that harvesting trees for power generation and biofuels production could actually *raise* atmospheric carbon levels in some cases. As a result, both Washington, D.C., and Brussels are reassessing how to count emissions from biomass combustion.

And yet, even with that policy challenge lurking, the biomass industry is quickly expanding, especially in the southeastern United States, where giant pelletizing plants are popping up to turn trees into a ready-to-burn export commodity. In 2011 the power company RWE, based in Essen, Germany, commissioned the world's largest wood pellet plant, near Waycross, Ga. The plant dries, crushes, and presses wood from local pine tree plantations into 750 000 metric tons of pellets annually—all of it destined for RWE power stations in the Netherlands and the United Kingdom.

Meanwhile, Enviva, based in Bethesda, Md., is fashioning itself into a formidable supplier of wood fuel. At the close of 2011, the firm began shipping pellets from its plant in Ahoskie, N.C., which produces 350 000 metric tons per year. Enviva is now building a still larger facility nearby in Northampton County, N.C., and is planning another in Courtland, Va.

European utilities are lining up for the pellets. Enviva has a contract to supply 480 000 metric tons to Belgium-based Electrabel, a subsidiary of the Paris-based GDF Suez Group. And in February, Germany's E.On signed a multiyear deal for 240 000 metric tons annually.

Power producers assert that blending biomass into

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3 x 10^-21 JOULES Minimum amount of energy released by the act of erasing a single bit of information at room temperature. First theorized by Rolf Landauer in 1961, this phenomenon was finally proven experimentally 50 years later.

coal at their plants reduces annual greenhouse gas emissions by displacing some fraction of their coal consumption. For example, RWE estimates that the pellets from its Georgia plant will "save" around 1 million metric tons of CO_2 per year. Such claims are based on the assumption that biomass energy is fundamentally carbon neutral because the carbon emitted during combustion is sucked back out of the atmosphere when the biomass grows back. To date, most regulators have agreed with the endorsement of the Society of American Foresters. The society argued in the *Journal of Forestry* last year that this simple accounting is reasonable in the United States, where forest inventories have increased year over year since the 1930s.

But many life-cycle analysts say that a closer look reveals several flaws in biomass power's zero-carbon designation. The biggest is an opportunity cost that comes with every tree that's cut down: the additional carbon dioxide that the tree would have sequestered had it been left to grow instead. "If you're cutting down trees and burning them, you're reducing your carbon [sequestering] stock," says Eric Johnson, editor of the *Environmental Impact Assessment Review*.

Even where net reductions are likely, they may be delayed by decades. A February 2012 study commissioned by the National Wildlife Federation and the Southern Environmental Law Center, modeled proposed biomass expansions in the southeastern United States. In the study scenario, export-driven pellet production jumps from nearly 1.8 million metric tons to more than 3 million metric tons, while the number of local biomass power plants—burning mostly forestry leftovers and other waste biomass—more than doubles from 17 to 39. The study projected that new trees would need 35 to 50 years to recover the carbon dioxide emitted from the increase in biomass consumption.

Similar case studies estimate that biomass payback will come slower still for trees harvested from slower-growing northern forests.

Delayed carbon reductions represent a policy conundrum for biomass power generation, which competes against other renewable energy sources like photovoltaics and wind power. Solar and wind pay back the carbon debt from their manufacture and installation in just 5 to 10 years. And fast-acting climate solutions are more valuable, because most climate scientists agree that global temperature change should be kept under 2 °C to minimize extreme impacts predicted by models, such as blistering heat waves and radical shifts in precipitation.

It's no surprise, then, that while the biomass power industry booms, international standards bodies and regulators are beginning to take a second look at its environmental bottom line.

—Peter Fairley

Graphene's New Rival

Molybdenum disulfide helps graphene transistors work better—and it makes good nanocircuits on its own, too

GRAPHENE HAS become the darling of the postsilicon crowd in the eight years since Andre Geim and Konstantin Novoselov isolated it by ripping Scotch tape off a chunk of graphite. But there are other two-dimensional nanowonders. Molybdenum disulfide (MoS_2), which can be pulled off a block of molybdenite through the same process, could offer new approaches to making high-speed logic circuits—on its own or in combination with graphene.

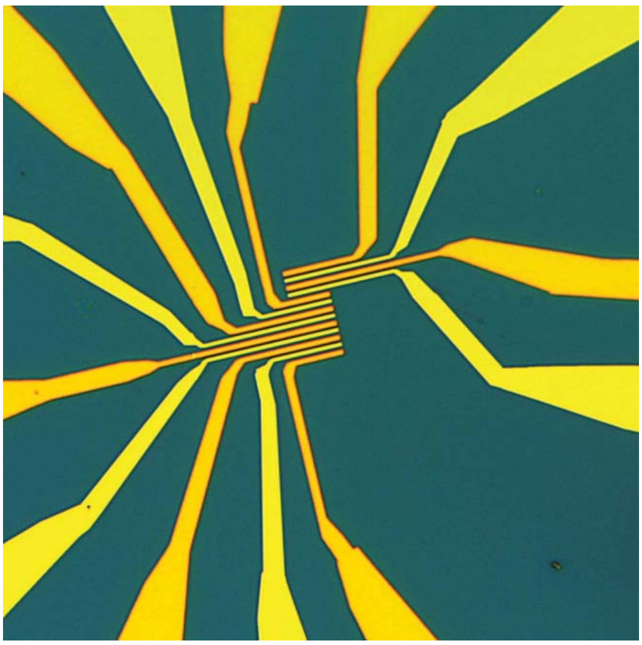
"We spent the last seven, eight years looking at how to make transistors out of graphene," Geim says. "But there was an elephant in the room—that you can't really switch off current in graphene."

Graphene's single atomic layer of carbon atoms allows electricity to flow rapidly, promising circuits that work far faster than silicon transistors. But it lacks a bandgap, meaning that it's hard to

OOH, SHINY! Slices of molybdenum disulfide [above] can be easily pulled off the bulk material and then fashioned into nanocircuits. *PHOTO: ANDRAS KIS*

740 PERCENT Power production improvement in converting wastewater to electricity from a new version of a microbial fuel cell. The new cell combines microbial and osmotic power generation.

update



ALTERNATIVE IC: Molybdenum disulfide transistors have been formed into logic gates. *IMAGE: ANDRAS KIS*

shut off the flow, making the on and off states of digital logic nearly impossible. Several approaches—using nanoribbons, quantum dots, or double layers of graphene—have been tried, but they are difficult, poorly developed, and tend to undermine the speed advantage.

So Geim and his colleagues at the University of Manchester, in England, tried a different design. They built a field-effect transistor with a vertical heterostructure—two layers of graphene separated by MoS_2 or boron nitride. Like graphene, those materials are considered two-dimensional because they're as thin as they can be; MoS_2, for instance, is a single atomic layer of molybdenum sandwiched between two single layers of sulfur. The material acts as a barrier, preventing charge from crossing. So ordinarily, the transistor is in the off state—no charge flows from one graphene layer to the other.

For the on state, the researchers raise the voltage of one of the graphene layers. That boosts the energy of the electrons in that layer, causing them to tunnel through the barrier into the other graphene layer. Since tunneling is by nature very rapid, the process should make for very fast circuits, Geim says. The device area could be scaled down to as small as the latest lithographic techniques allow, which is better than today's silicon circuits, Geim claims.

Using boron nitride, the ratio between on and off was only about 50, but with MoS_2 it was about 10 000, sufficient for some logic circuits. But Geim isn't wedded to MoS_2. The experiments, published in *Science* in February, were only a proof of concept, and there may be some material that works even better.

But MoS_2 might work just fine on its own, according to Andras Kis, an assistant professor in the Laboratory of Nanoscale Electronics and Structures at École Polytechnique Fédérale de Lausanne, in Switzerland, who presented research on MoS_2 devices at the American Physical Society's March meeting in Boston. Instead of using MoS_2 as the insulating filling of a three-layer sandwich, his team used a single layer of the material as the semiconductor channel that connects source and drain in a transistor, achieving an on-off ratio of 100 million. Combining two to six of these transistors, he made integrated circuits—inverters, NOR gates, and other logic. He says it should be possible to make channels smaller than 10 nanometers in length, perhaps as tiny as 5 or 6 nm, smaller than silicon is likely to ever get. The smaller transistors are, the more can be crammed onto a chip.

Unlike graphene, MoS_2 does have a bandgap, which makes switching more straightforward. In fact, at 1.8 electron volts, its bandgap is higher than silicon's (1.1 eV). It's actually higher than you can get in graphene, if you make the graphene into thin ribbons, as some researchers do, Kis says. The higher bandgap means switching would require less power, which could be attractive for mobile applications.

"It's probably not going to be as fast as graphene, because it doesn't conduct that well, but I think it will be comparable to silicon," Kis says. And if the circuits are smaller with the same speed and lower power consumption, that's still an improvement over silicon.

Researchers have shown that MoS_2 also resembles graphene in having attractive mechanical properties, though not quite to graphene's extremes. It's 30 times as strong as stainless steel, where graphene is 100 times as strong. It's also very flexible; it can bend to a deformation of 10 percent without breaking, whereas most semiconductors (graphene excluded) break at less than 1 percent. "It's more like a polymer in that respect," Kis says, adding that it might be used in flexible electronics. He's not expecting MoS_2 to displace graphene as the new wonder material. But it still may help pave the way to a postsilicon future for electronics. —Neil Savage

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history

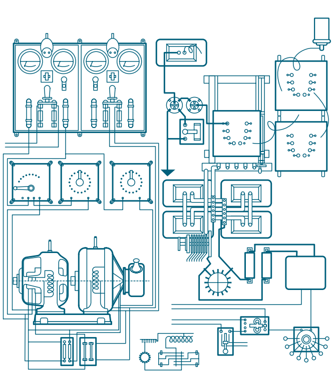
"PLEASE RUSH ALL POSSIBLE ASSISTANCE"

How the sinking of the *Titanic* sparked a century of radio reform

WHEN THE RMS *TITANIC* scraped an iceberg on the night of 14 April 1912, its wireless operators began sending distress calls on one of the world's most advanced radios: a 5-kilowatt rotary spark transmitter that on a clear night could send signals from the middle of the Atlantic to New York City or London. The equipment was owned by Marconi's Wireless Telegraph Co. and operated by two of its employees, Jack Phillips and Harold Bride.

What Phillips and Bride lacked, however, were international protocols for wireless communications at sea. Shipboard operators were still an unregulated novelty, and they reported to their companies, not to the ship captain. They sent business and personal messages alike using assorted spark transmitters over various wavelengths. The vast majority of ships had only one radio operator, who was obligated to serve only a 10-hour shift each day. Efforts to regulate wireless at sea drew challenges from governments and corporations—most notably Marconi's own company.

But after a series of maritime accidents in the early 20th century, the need to standardize procedures and systems for wireless maritime distress became increasingly apparent. The *Titanic's* sinking accelerated a process that to this day continues to improve communications technology at sea. —*Alexander B. Magoun*



The *Titanic*'s Radio System
This schematic shows a typical Marconi marine 5-kilowatt wireless transmitting set, of the type installed on the *Titanic*. Much of the transmitting equipment was kept in a separate cabin, known as the Silent Room, while the operators worked in the Marconi Room.

MAY 1897: Alexander Popov demonstrates shore-to-ship wireless telegraphy in the Gulf of Finland.

24 DECEMBER 1898: Guglielmo Marconi demonstrates ship-to-shore wireless contact near Dover, England.

11 MARCH 1899: The *Elbe* runs aground in the English Channel. The East Goodwin Lightship sends the first wireless distress call.

1 FEBRUARY 1904: Marconi's company adopts "CQD" to signal maritime distress. "CQ" is a homophone of *sécu*, short for *sécurité*, used to designate important telegraph messages.
▬•▬• ▬▬•▬ ▬••

1 APRIL 1905: Germany adopts "SOS" as its distress signal.
••• ▬▬▬ •••

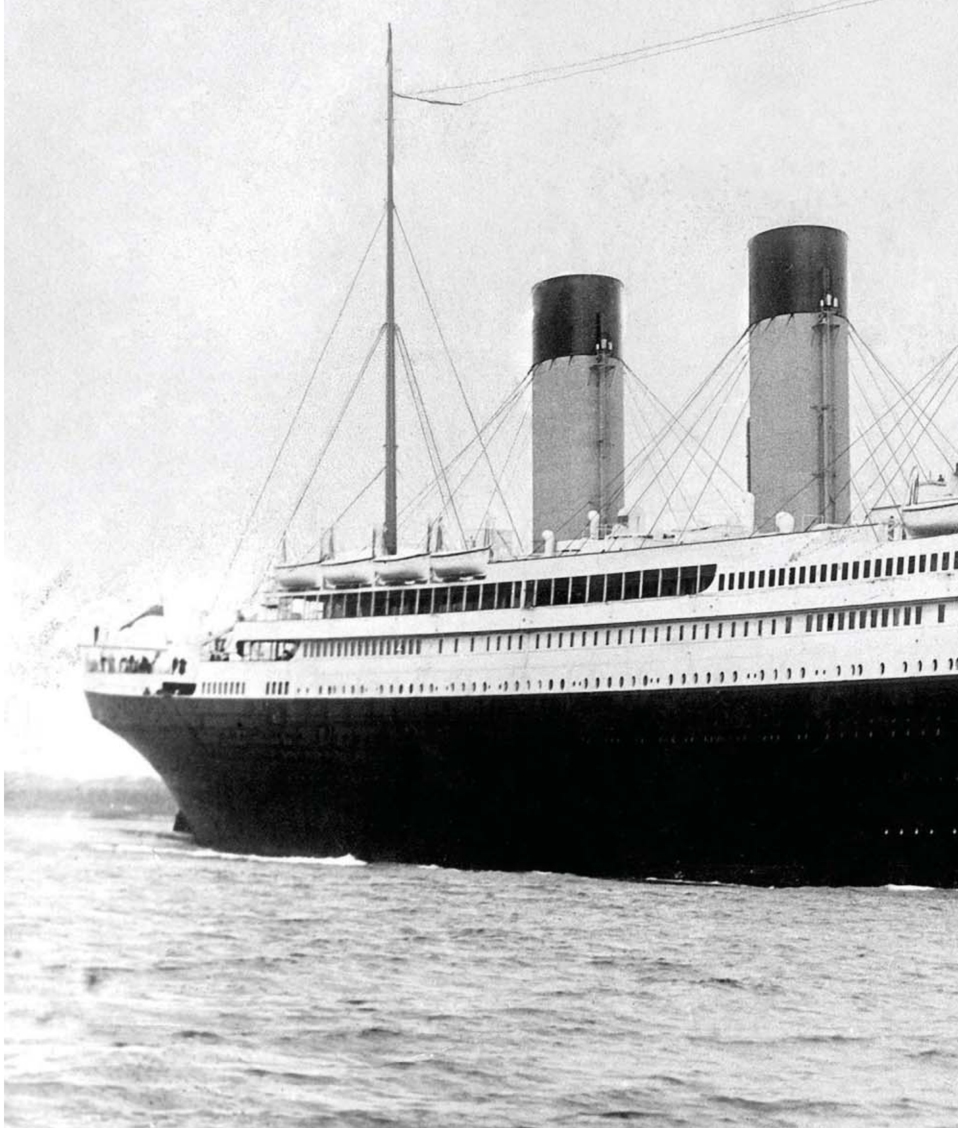
24 JUNE 1910: U.S. President William Howard Taft signs a law requiring ships visiting U.S. ports to install wireless equipment.

10 APRIL 1912: The RMS *Titanic* sets sail from Southampton, England. Radio equipment includes a synchronous rotary spark transmitter driven by a 5-kilowatt motor-generator that draws 100-volt DC from the ship's lighting circuit and converts it to AC. The setup is powerful enough to send Morse code signals up to 700 kilometers by day and 3200 km by night.

The transmitter generates radio waves by means of spark gaps: Electrodes mounted on a rotating metal disk driven by the motor-generator pass by two electrodes fixed to an outer cylinder; as the telegraph key is depressed, high-voltage sparks jump the gap between the fixed and rotating electrodes. Signals travel through a four-wire, 180-meter-long Marconi twin "T" type antenna, strung between the ship's two 60-meter masts.

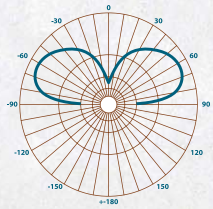
14 APRIL 1912: The *Titanic* strikes an iceberg at 11:40 p.m. Radio operator Jack Phillips begins transmitting "CQD MQY" (*MQY* were the *Titanic*'s call letters) 35 minutes later. At fellow operator Harold Bride's suggestion, Phillips also begins sending "SOS MQY."

The *Frankfurt* is the first to answer the call, followed by the *Olympic* (*Titanic*'s sister ship), the *Carpathia*, the *Baltic*, and several others. But the ship closest to the *Titanic*, the *Californian*, does not respond; its radio operator had switched off his equipment for the night 10 minutes before the *Titanic* struck ice.

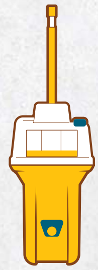


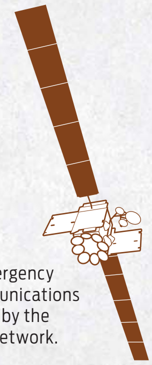
15 APRIL 1912: The *Titanic* sinks at 2:20 a.m. Of the 2200 or so people aboard, about 1500 die. The *Carpathia* arrives at 4:00 a.m.

16 APRIL 1912: David Sarnoff, wireless station manager at Wanamaker's department store in New York City (and future president of RCA), informs a supervisor that the *Titanic* has sunk and that the *Carpathia* is the only ship with survivors.



1948: A United Nations convention adopts 2182 kilohertz as the new distress frequency.





1988: Emergency ship communications are carried by the Inmarsat network.

JULY–AUGUST 1912: On 5 July, the International Radiotelegraph Convention in London adopts the distress signal "SOS," along with continuous staffing of ships' wireless stations. Within several weeks, U.S. laws are similarly updated, with new provisions requiring radio stations and operators to be licensed.

1 NOVEMBER 1974: New rules require ships over 300 metric tons to carry satellite-based emergency radio beacons and search-and-rescue transponders.

2004: Ships now must have two means of transmitting ship-to-shore distress alerts: at 156.3 megahertz and at 406 MHz or 1.6 gigahertz.

For a complete list of references and sources, see http://spectrum.ieee.org/titanicsources0412.

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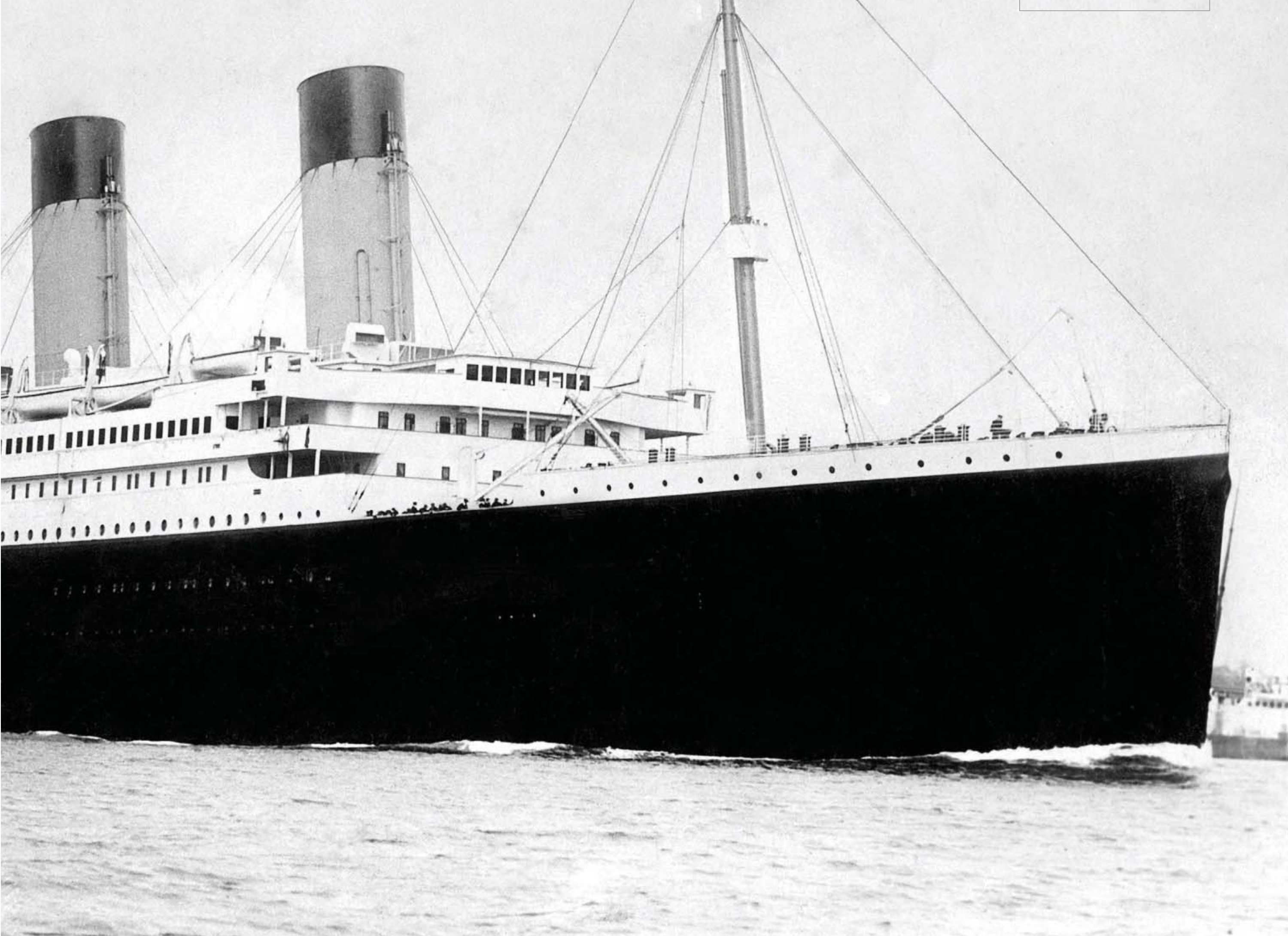


tools & toys

TABLET RASA: Suneet Singh Tuli is the founder and CEO of DataWind, which manufactures the $50 Aakash.

DARYL VISSCHER/REDUX

SEARCHING FOR THE AAKASH

Yet another ultracheap computer project falls short of the mark

EARLY IN January 2012, Suneet Singh Tuli, CEO of DataWind, a small computer company based in Montreal, told *The Economic Times* of India that advance orders for its 2500 rupee (about US $50) tablet computer had reached 1.4 million units in just two weeks—besting the record of Apple and its iPad. The tablet, dubbed the Aakash (Hindi for "sky"), had been promoted by the Indian government through a contract to DataWind as an ultralow-cost computer for the country's 1.2 billion citizens. We contacted *IEEE Spectrum*. Would it be interested in a review? Of course it would.

The tablet was released this past October. Also that month, Kapil Sibal, minister of human resources development in New Delhi, had announced in a press conference that around 10 000 samples were being given to students in various engineering institutes to test the functionality of the tablet.

The three of us set out to find a unit. After a fruitless week of calling around Delhi, we learned that the Indian Institute of Technology Rajasthan, in Jodhpur, had samples available.

So after an 11-hour train ride to Jodhpur, we were hospitably entertained by Prem Kalra, the director of IIT Rajasthan, and his colleagues. Kalra and his group had first conceived of the Aakash tablet, and they told us its history.

Inspired by the One Laptop Per Child project, in 2006 the Indian government opened bids for ultracheap computers to the premier technical institutes across India. Kalra, then teaching at IIT Kanpur, won the competition.

Kalra moved the project to Jodhpur in 2009 when he assumed the post of director of the new IIT there, and he continued to lead a small team to develop the tablet. Based on Kalra's plans, in early 2011 the Indian government contracted with DataWind to manufacture the tablet.

We were not allowed to take the tablet from the

IIT campus, but we could use it there and meet the development team. So there we sat, with pens and paper, a camera, and scores of questions that two of the team's research engineers patiently answered.

Aakash-1 is a basic 7-inch tablet running Android 2.2 on a 366-megahertz Conexant processor with a microSD slot, two standard USB ports, an audio port and input jack, and a mere 256 megabytes of memory. It has Wi-Fi connectivity but no Bluetooth or cellular service.

The key word is basic—and painfully slow. Slower even than cheap mobile phones in India, which typically come with 699-MHz processors. Its limited battery life—a maximum of 2.5 hours, which falls to 1 hour and 20 minutes with video or other applications running—is disappointing for a device that's supposed to be used in villages where access to electricity is sporadic at best.

And it's poorly built. The touch-screen cover was attached badly, making simple clicking difficult, to say nothing of push-and-drag sequences. The tablet heats up excessively after 45 minutes of use, and applications often hang. According to the engineers, the touch-screen cover frequently comes off while the tablet is being charged, because of the heat. Also, the tablet has no access to Android Market, which sells apps and media, so it will be difficult to upgrade software and service the product.

Such problems might be expected in a prototype. Unfortunately, DataWind raised higher expectations for the Aakash, in us, and evidently in the government as well.

A couple of days later, Kalra met again with one of us. Although constrained by confidentiality—he manages the contract with DataWind and is in charge of contracts for the next model—he clearly viewed the Aakash-1 as the first iteration of an eventually successful tablet. In fact, in his laboratory we saw prototypes of improved versions that will be the basis of the next round of contracts.

The obviously premature release of Aakash-1 and the attendant hyperbole has mired Kalra, the government, and DataWind in controversy. According to newspaper reports, it is unlikely that any more Aakash-1s will be produced, and the government is reportedly considering putting on hold a tablet-related letter of credit to DataWind.

Meanwhile, a tender has been prepared for a contract for an improved tablet, for which other vendors would compete along with DataWind, Kalra indicated. The company, for its part, is protesting what it feels are the tender's onerous performance standards. As this is being written, meetings are under way to resolve the issue.

Any major improvements in the tablet, let alone satisfying the reported water resistance and other requirements of the tender, will surely raise the selling price. Even assuming paper-thin profit margins, the price will go well above the target of $50 and approach that of competing devices, such as the just-released $100 One Laptop Per Child XO-3 tablet, which has garnered favorable reviews.

Whatever the outcome of this dispute, Kalra remains passionate about using tablets to bridge the digital divide, so that "every last person, usually a woman," can communicate, download educational material, send photos of themselves to physicians, file their taxes—all on this one device.

That would require a more competent tablet than the Aakash-1, not to mention electricity, Internet access, and service and repair capabilities. Ways must also be found for the impoverished and poorly educated people in the target audience to use the tablet to improve their lives.

The Aakash won't be in your local store anytime soon, and when it is it will probably cost a lot more than $50. Meanwhile, DataWind has announced a similarly configured commercial version called the Ubislate ($60), which will also include a cellphone. The company is accepting advance orders now.

—Jairaj Bhattacharya, Chiteisri Devi & Kenneth R. Foster

A version of this article ran online in January.

ONE LAPTOP PER CHILD

And a Child Shall Lead Them

Like Microsoft, the One Laptop Per Child project seems to have gotten it right in version 3

The original OLPC, introduced in 2007, underwhelmed and underperformed. Later models improved the processor and reduced power consumption, two key complaints of early users. But the price never went below US $200.

The OLPC XO-3 tablet, on the other hand, has been bowling over reviewers since its debut at the January Consumer Electronics Show—and with good reason.

With a rubber back and sides, a transflective touch display, waterproofing, and a removable solar-panel cover that can be left outside to recharge, it's designed for harsh environments that have limited access to electricity. Its charging port can even take a hand crank, which gives 10 minutes of use for every minute of cranking. It can run Android as well as its own operating system (Sugar OS) and has two cameras plus Micro- and regular USB ports. Best of all, it might come in at less than $200. —*Steven Cherry*

hands on

EASY BAKING: A PIC microcontroller is almost all you need to turn a toaster oven into a reflow oven.
PHOTO: TOM BURKE

THE POOR MAN'S SOLDER REFLOW OVEN

A cheap controller and a Walmart toaster oven kept the price down

LAST TIME I tried soldering small resistors was an experience, I'll tell you what. They were almost as likely to stick to my soldering iron as they were to stick to the board, and I burned plenty of them in half.

Admittedly, I don't have the world's best soldering station. In fact, what I have is a junky old pencil iron, not much better than what you'd buy at RadioShack—no adjustable temperature control and no replaceable tips. I also don't have US $500 to invest in upgrading my station, but even if I did, it wouldn't help much. I'm getting older—and so are my eyes.

The solution was obvious: Build a reflow oven!

First off, let's get all the disclaimers out of the way: This project involves dangerously high voltage at high currents! Be careful!

The plan was a simple one: Design a controller. Put it in a toaster oven. I searched the Internet and found some similar projects. This was comforting, as it meant that the toaster oven would get warm enough to do the job.

I decided to use a PIC microcontroller (from Microchip Technology) and a type K thermocouple as the temperature-sensing device. I did some research on thermocouples. It turns out that I'd need an "ice reference" of some sort. I chose an Analog Devices AD595.

This thing was going to be fully buzzword 3.0 compliant, with three preset control curves (lead/tin, RoHS, and one manual-entry curve), an LCD on the front, and RS-232 communication to monitor the temperature profile from a PC. In other words, I would be able to flow standard lead-tin solder and the "green" solders, and do some custom curves for components that require it (like big, honkin' FPGAs). I spent some time putting together block diagrams. I even got so far as selecting most of the parts. The total cost would be about $400.

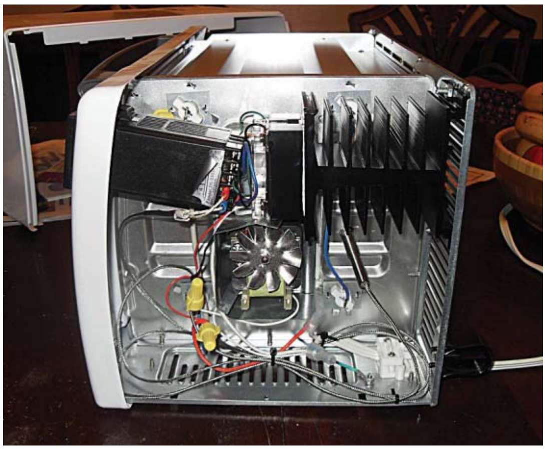
I was just starting to put together schematics when a friend at work ruined the whole project (thanks a lot, Ryan). He pointed me to a company, Annex Depot, that sells PID ramp/soak controllers for about $75. Last time I looked at such things was a couple years back, and they didn't go for less than about $500. Ain't Moore's Law great? Unfortunately, the documentation left something to be desired—it was poorly translated into English from Chinese. Also, the unit that would best fit inside the oven housing was out of stock.

I looked around some more and found another company, Auber Instruments, that sold a similar product (SYL-2352P) that was American-made and had much better documentation, for the same price. Auber also sells the thermocouples (with a 4-inch probe tip), 40-ampere solid state relays (SSRs) for plenty of margin, and SSR heat sinks, all cheaper than I found elsewhere.

Wow! Total cost (including a spare thermocouple and the toaster oven) would be right about $200. I spent $153.85 (including shipping) with Auber and a bit less than $50 at Walmart for a Black & Decker toaster oven with an internal convection fan (to minimize hot spots). It took me less than a day to integrate the system. It took me most of another day to get a reasonable control heating profile (lead-tin) out of it.

Removing the oven's screws is one of the more interesting parts of this project. The bottommost screw on the back isn't a Phillips, it's a "star"—presumably to keep morons like me from cracking the case open and getting electrocuted.

The next trick is the LRF (little rubber feet). These little plugs pull out to access the screws underneath. My



BEFORE AND AFTER: There's not much to the oven's innards, so there's plenty of room for rewiring.
PHOTOS: TOM BURKE

oven had a piece of bent metal that scratched my kitchen table. Fortunately, it's not a new table, and I have kids, so my wife didn't notice.

With the cover off, you can see the innards. There's not much in there. To the far left, you can see the backs of the controls; in the middle is the fan motor with a cooling fan and protective shroud. See the thermal shield around the black wire? There's a fusible link in there. I took it out. On the far side of the oven, you can see the metal bars soldered to connect the heater elements in pairs (top and bottom). The long white thing is the door-hinge mechanism—it's attached to a spring in the back.

It's easy to pull off the knobs by inserting two standard screwdrivers opposite each other and prying them up. See those metal tabs? Straighten them out as best you can and the metal cover will pop right off the front. You can then remove the controls.

Use the ramp controller as a template to demarcate the area to be cut out—the original opening for the neon lamp was almost perfectly sized for the controller. I used a Dremel tool with cutting disks. (Be sure to wear safety glasses!) Deburr the opening with a steel file.

I used the old control cover as a template for a new control cover, which I made with some 25-millimeter aluminum sheeting from Home Depot. Don't forget to make tabs to hold it on. (Note: You can bend and straighten those tabs only about three or four times before they break.)

We're almost there. Drill a hole into the thermal compartment and use two wrenches to install the thermocouple. Bend it into the airflow, just below the shelf.

Connect the wiring to the SSR according to the schematic (available online). You need to do this prior to mounting the relay in the chassis because of clearance issues. Note that the fan is wired to run the entire time the system is plugged in. You may also want to add a power switch—it should interrupt power to just the controller and the fan.

The two rear elements are already wired together—just cut their connection to the AC power cord and rewire it to the SSR. Connect the other side of that cut connection to the other side of the SSR; add another wire in that side's connection to supply the controller. When the SSR is energized, it will supply a path to ground, allowing the elements to be powered. Connect the two control wires to the SSR, using different colors so you don't get them confused later.

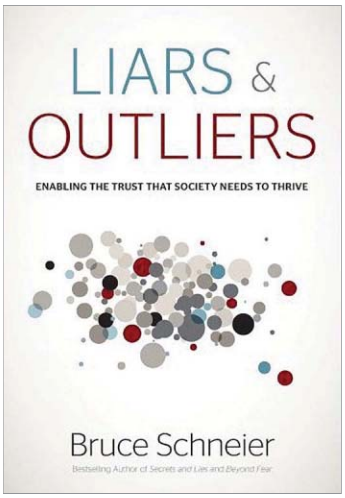
Mount the SSR on the heat sink, using the supplied sink grease and screws, and drill some holes in the back cover to mount it with machine screws. I would have mounted the sink to the floor of the oven, but that was where the power line came in. Be careful of the fan shroud—there's just enough room to install the SSR.

Use some heavy gauge wire and wire nuts to connect the top- and bottom-forward heater elements together. Wire them to the remaining AC wire that you cut loose earlier—string off another wire to supply the controller. Pull the controller wiring through the mounting bezel (but not the thermocouple wires), and connect them to the controller outside the unit. Slide the controller into the chassis, pulling the connecting wires up and out of the way of the fan. Install the thermocouple wires on the controller—blue on pin 5, red on pin 4. Install the mounting bezel. Finish wiring the guts, if necessary.

Reinstall the cover. (Make sure you correctly reinstall all the screws and feet.) After a short self-test, the controller should come up as described in the instruction manual. If you did everything correctly, no breakers will trip and no sparks or smoke will come flying out. You can follow the controller instructions to set a steady-state temperature and then test the control. If it works, you're done!

—Tom Burke

books



Tangled Web of Trust

Bruce Schneier explores the relationships between trust and security

Liars & Outliers
Enabling the Trust That Society Needs to Thrive
By Bruce Schneier; Wiley 2012; 384 pp.; US $25; ISBN: 978-1-1181-4330-8

Bruce Schneier is a security icon, the cryptological equivalent of action-movie superstar Chuck Norris, able to straighten elliptic curves with his bare hands. *Liars & Outliers* isn't the book you'd expect from someone whose portrait adorns posters—nor from the coauthor of several important encryption algorithms (one of them a finalist for the next generation of national encryption standards).

On his blog, Schneier reminds us almost daily that protecting your secrets with a 4096-bit key doesn't do much good if you have to tape the new pass phrase to your monitor, and that an unforgeable ID card is of little value if someone can get one by slipping 20 bucks to a file clerk. In *Liars & Outliers,* however, he takes an almost Aristotelian step back from those frontline concerns to discuss the first causes of security: the kinds of trust that security measures help to enable and why we secure things in the first place, even when—indeed, especially when—we know that security will never be perfect; and also why we probably shouldn't even want security to be perfect.

Schneier points out how remarkable it is that we *do* generally trust one another. We do it each and every day, and almost invariably that trust is repaid. Cable-TV technicians don't pillage the houses they're given free access to, certified public accountants don't generally loot their clients' bank accounts, and waiters don't poison patrons, no matter how rude they are. Though the odds of getting caught are small, such people and their institutions almost uniformly behave honestly. Even if many of us have larceny in our hearts, we don't exercise it with our hands.

By and large, locks, alarms, and the other measures we typically think of as "security" only come into play, Schneier argues, when social pressures such as altruism, ethical codes, and concern for reputation or self-image fall short. As the scale of society grows from local to metropolitan to global, however, these social bonds diminish and the need for security grows.

This sounds like an argument for maximum lockdown—at least in cities—limited only by the potential cost of overzealous enforcement. Yet Schneier shows how the alternative extreme would not only be maximally unpleasant but also fail to deliver the greatest security. Looked at from the perspective of game theory, reducing the number of social predators just makes the pickings richer for the "hawks" who remain. And from an anthropological viewpoint, it is the attackers' very intelligence and resourcefulness that spurs defenders to progress. So we're left with an unending arms race.

Then Schneier goes a step further: Because we are all simultaneously members of many different subsets of society with competing interests—family, friends, colleagues, party, nation—we sometimes need security to fail. If Lockheed Corp. executives in the 1940s had had the clout and the personnel to make sure that every engineer filled out all the forms and followed all the approval procedures that corporate rules normally require, the company's fabled Skunk Works would have been impossible, and the P-38 fighter and a dozen other planes would never have been designed. If Muammar Gaddafi's security forces had been able to perfectly triangulate every mobile Twitter message, opposition members would have been arrested after their first tweet.

In other words, sometimes rule breakers are a threat to society, and sometimes they are its best hope. If that sounds like Thomas Jefferson's "I would rather be exposed to the inconveniences attending too much liberty than to those attending too small a degree of it," we can still thank Schneier for updating this eternal truth for a digital age.

—Paul Wallich

A version of this article appeared online in February.

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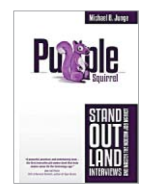

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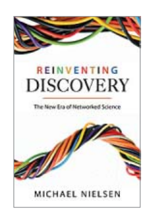

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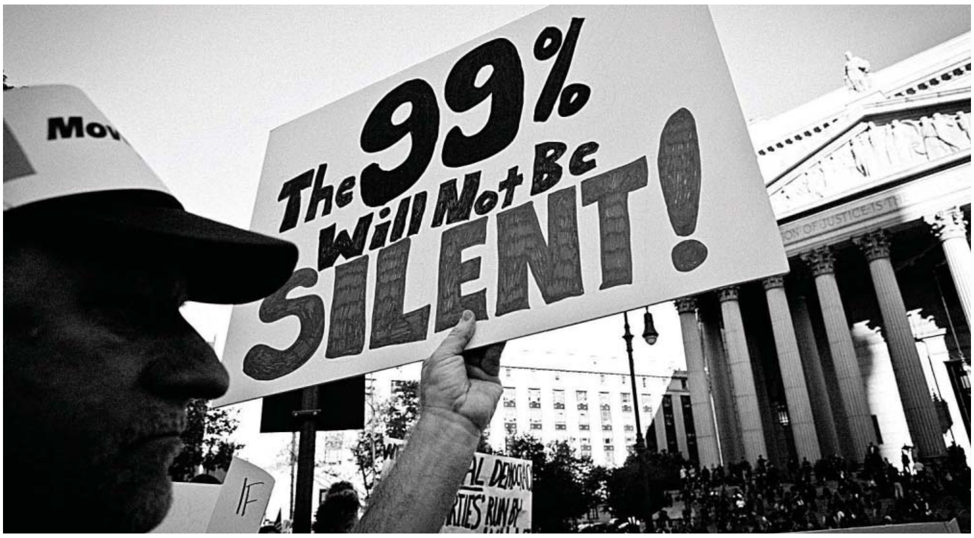

Occupy English

On September 17, we want to see 20 000 people flood into lower Manhattan, set up tents, kitchens, peaceful barricades and occupy Wall Street for a few months.
—Adbusters.org, 13 July 2011

Two months after the above call to action appeared on the blog of *Adbusters* magazine, thousands of protesters dutifully and gleefully descended on lower Manhattan (but not, alas, Wall Street). They sought a North American **Tahrir moment**, a revolutionary tipping point on the model of the Egyptian protests that centered on Cairo's Tahrir Square. The Occupy Wall Street (OWS) movement created tremendous buzz before packing up due to police pressure and cold temperatures. Whether OWS was a success or failure will be up to the historians to decide. My decidedly more modest goal is to check out its linguistic innovations.

Occupy is an old word, of course, but by late 2011 it had come to have a new meaning: "to take possession of and remain in a place without authorization as a form of protest." In fact, the protesters soon largely abandoned the "Wall Street" portion of the name, and the protests became more generally known as the capital-*O* **Occupy movement**. Indeed, the word became so iconic that the American Dialect Society voted it Word of the Year for 2011.

The protesters called themselves **the 99%** and **99 percenters** (or **99%ers**), and the target of their wrath was **the 1%** or the **1 percenters**, the class of people who are the top 1 percent of income earners. (A conservative rejoinder soon made the linguistic rounds: **53 percenter**, a person who is part of the 53 percent of households that pay income tax.)

The goals of the 99 percenters were both vague and diverse, but they could be summarized (as in the original *Adbusters* blog post) as seeking a restoration of democracy from the current system of **corporatocracy**. This two-syllables-too-many term (the punchier variation is **corpocracy**) refers to a society in which corporations have substantial economic and political power. A similar coinage is **plutonomy**, an economy that is driven by or that disproportionately benefits wealthy people, or one where the creation of wealth is the principal goal. The protesters viewed their wealthy bêtes noires as **lucrepaths** (a blend of *lucre* and *psychopaths*).

"We are the 99 percent" became the rallying cry of the **occupationistas**, but just who are they, anyway? They are the **precariat**, a mashup of *precarious* and *proletariat* that refers to people who have little or no job security. They're the people doing the **ghost work** that after a round of layoffs or firings must now be handled by the remaining staff. More often than not this leads to **workweek creep**, the gradual extension of the workweek caused by performing work-related activities during nonwork hours (a phenomenon also known as **job spill**), and **weisure** (a blend, literally and linguistically, of *work* and *leisure*).

Other 99 percenters are stuck in **stop-loss jobs** that they take only to prevent the continued erosion of their savings. Slightly worse is the *GOOD job* (1995)—a "get out of debt" job. Of course, the recent economic downturn has meant that many among the protesters don't have jobs at all, particularly men, who were hit harder than women during the recession, thus requiring the term **mancession**. Don't, however, confuse a 99 percenter, male or female, with a **99er**, a U.S. citizen who has been unemployed for at least 99 weeks and so is no longer eligible to receive unemployment benefits. Such a person is said to be in a state of **worklessness**, the condition of not only being unemployed but also having few prospects. All he or she can do is **post and pray**, which involves uploading a résumé to an online job site and hoping to get a response.

The Occupy occupants also bequeathed the protest-friendly terms **human microphone** (the repetition of a nonamplified speech by successive groups so that people farther away can hear) and **twinkling** (waving hands with fingers pointed skyward to signal applause or agreement). The language is richer for these new additions to the vocabulary, but it remains to be seen if this movement can create more than just linguistic wealth. ❑

RADHIKA CHALASANI/REDUX

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FORTUNE
10 TECH TRENDS TO WATCH IN 2005
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Marissa Mayer: Google's Chic Geek

This self-proclaimed "girly girl" runs one of Google's fastest-growing services

By TEKLA S. PERRY

THE RANKS OF BONA FIDE international celebrities in technology is rather small, if by "bona fide" you mean people whose fame has something to do with actual technological acumen and achievement. But now let's draw up a list of all the *female* bona fide international tech celebrities:

1. Marissa Mayer.

End of list.

Mayer was the first female engineer and among the first 20 people hired at Google. She was a major force behind its user interface. For 10 years, she ran its core search business while the company demolished such competitors as AltaVista, Lycos, and Excite. Now, at age 37, she's in charge of one of Google's hottest bunch of technologies: location and local services. She oversees more than 1000 engineers and product managers who are refining Google Maps, Google Places, and Google Earth and also developing the technology behind applications that may revolutionize the mobile Web as much as the search engine transformed the original one.

Mayer is also one of the world's more unusual pop stars, a brainy blond paparazzi magnet that gossip site Gawker once referred to as "Google's star-dappled moon queen." She's been on the cover of *Newsweek*. For her wedding two years ago, covered in *Vogue*, superchef Jean-Georges Vongerichten personally prepared the food. Her brassy laugh, a low-pitched machine-gun staccato, is downloadable as a ringtone. Her speech, too, comes at you in a rapid-fire volley, as she pulls precise dates and statistics from the encyclopedia of her brain without a perceptible pause.

Tech caught Mayer's attention when she was a cherubic 7-year-old in Wausau, Wis. A playmate's brother, a stunningly precocious 4-year-old, had taken a talking toy calculator that normally spouted profundities like "Two plus two equals four" and rewired it to greet him by name. "I thought that was amazing," Mayer recalls. In third grade she wrote little programs that drew simple patterns using a Commodore 64 computer. Programming came easily for her, but it was in medicine, not engineering, that little Miss Mayer decided her future lay. "I made the decision that I was going to be a pediatric neurosurgeon who taught at a medical school while taking exceptional cases," she recalls. She was 12 years old.

So it was that six years later Mayer entered Stanford University on a premed track. She bought her first computer in 1993 during her freshman year—a Macintosh Centris 610. "I couldn't find the on/off switch," she says.

At Stanford, during the last quarter of her freshman year, she took CS 105A—Computer Science for Non-Majors—simply to fulfill a graduation requirement. They did a little simple programming, she recalls, and the professor, Stephen Clausing, also introduced them to Mosaic, the first popular Web browser, then brand new, by asking them to find out the price of country-fried steak at a nearby restaurant.

Mayer got an A in the course, and more important, she really liked it. What she hadn't realized at the time was that she had taken her first steps off her planned path to premed.

BUT IT WAS LESS Mayer's innate talent than simple frugality that pushed her toward computer science. Talking with friends back home in Wisconsin between her freshman and sophomore years, she discovered that she was getting basically the same premed education she would have gotten at the University of Wisconsin, but at a vastly greater cost.

On the plane back to California at the end of that summer, perusing Stanford's course catalog, she discovered a major called symbolic systems. An amalgam of computer science, psychology, linguistics, and philosophy, it was designed to look at how people think and how a computer might emulate that process. Here, surely, was an education worth Stanford's sky-high tuition.

She took her first linguistics course in the fall, along with one last biology course, just to be sure. But she didn't venture back into computer science until the winter of her sophomore year, waiting until the popular professor Eric Roberts would be teaching the introductory programming course.

During that class, Roberts ran three programming contests; Mayer's entry in the graphics programming challenge came in second. She created a program that included a few different screen savers, one with shapes, one with fireworks, and another with words selected by the user. It didn't revolutionize computer graphics—toasters had been flying across idle screens for several years at this point—but writing your own graphics code wasn't then a trivial task. Roberts invited the winners and runners-up to dinner, and Mayer says attending that dinner at Roberts's house was almost as good as winning first prize (an automatic 100 percent on the final).

At dinner, Mayer says, Roberts told her she should continue in the field she clearly excelled in. He recalls that he hadn't noticed Mayer before the contest but was immediately struck by her entry. (The department went on to use it as an assignment for nearly 10 years: Successive waves of students have had the chance to re-create Mayer's code for fireworks.) Mayer's exit from premed was now complete.

In Stanford's computer-science circles she stood out, and not just because of her brains. One day she found herself amused by a campus newspaper article about

PREVIOUS AND THIS PAGE: GABRIELA HASBUN

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Close-up: Marissa Mayer

CURRENT JOB: Vice president of location and local services, Google

DATE OF BIRTH: 30 May 1975

BIRTHPLACE: Wausau, Wis.

HEIGHT: 173 centimeters (5 feet 8 inches)

FAMILY: Married to Zachary Bogue

EDUCATION: B.S. symbolic systems, 1997, and M.S. computer science, 1999, both at Stanford University

FIRST JOB: Checkout girl at Crossroads County Market, Wausau, Wis.

BIGGEST SURPRISE IN CAREER: The scale of it all

RECENT BOOK READ: *Delivering Happiness* by Tony Hsieh, founder of Zappos

FAVORITE FOOD: Grilled cheese sandwiches

FAVORITE MOVIES: *It's a Wonderful Life* (1946), *Say Anything* (1989), *Willie Wonka & the Chocolate Factory* (1971), *Moulin Rouge* (2001), *Legally Blonde* (2001)

MAJOR AWARDS: Young Global Leader of the World Economic Forum; *Glamour*'s Woman of the Year for 2009; Juliette Gordon Low Award from the Girl Scouts in 2008; honorary Ph.D. from the Illinois Institute of Technology, 2009

local celebrities, the folks that everyone can't help but notice—"like the angry guy who yells at everyone who bikes by him," she recalls. Most of the descriptions provoked a smile of recognition, but she found herself puzzling over one of them: "the blond woman in the upper-level computer science classes." Befuddlement soon gave way to shocked recognition. "Oh, that's me!" she remembers marveling, her bright blue eyes even now wide with surprise at the memory.

For her undergraduate thesis she built travel-recommendation software that advised users in natural-sounding human language. A user could tell the system that he preferred a nonstop flight from San Francisco to Boston but could also specify where he'd choose to stop if a nonstop flight was unavailable.

Mayer continued straight into a master's program at Stanford. While in that program, she spent a summer interning at Ubilab, in Zurich, then the research arm of the Swiss investment firm UBS. Her boss, Matthew Chalmers, asked her to build a piece of software that would track people's paths as they browsed the Web without retaining any information about them. Basically, the software followed a user's path from A to B to C, so that it could later use that information to suggest to someone else, at B, to consider A and C. UBS intended to use the software internally; it hoped such tools would let traders zero in quickly on the information they needed. If a trader started the morning checking the price of gold, then read a report on projected gold prices, and went on to check a report on oil futures, the next person who looked at the price of gold might be directed straight to the report on oil.

Mayer wrote a program and distributed it to the 30 or so researchers in the lab to test. It was pretty hot stuff for its day. "It was basically the equivalent of Amazon's book recommender," Mayer says, "which came out at around the same time."

THAT PROJECT LED MAYER TO GOOGLE, but via a rather circuitous route. Back at Stanford, she told Roberts, her introductory computer science professor, how she'd spent her summer. Roberts suggested that she meet some graduate students with offices in the computer science building who were doing something similar to what she'd done at UBS. Like her, they weren't looking at people's Web destinations but rather the paths people took from place to place, and they were trying to turn those paths into recommendations, rankings, and relevance. "I can't remember the name of the company," Roberts told Mayer, but "it's two guys, Larry Page and Sergey Brin."

"I suggested that Marissa go look up these guys, whatever their company was called," Roberts recalls. But she didn't.

"I was like, 'I just got back in the country,' " Mayer explains, channeling her younger self. "I'm teaching for the first time. I don't have time to mess around with a start-up."

She didn't give Page and Brin any more thought until the following April, just two months before her graduation. She was sorting through 14 job offers, from Oracle, McKinsey, and Carnegie Mellon, among others. She did what most people do when they're overwhelmed—she procrastinated. Finally, she set a deadline of 1 May. She decided not to look at any more job offers, deleting the e-mails as they came in—except for one on 22 April 1999.

"Largely owing to a long-distance relationship and a really bad bowl of pasta, I found myself in my dorm room, distracted," Mayer says. Sitting in front of her computer, scrolling through her e-mail, she hit the space bar instead of the delete key and found herself looking at a message from Google. "I realized it wasn't a form letter. It said: 'We've spoken to some professors who said you were someone we should be talking with.' " It dawned on Mayer that this was the company Roberts had told her about six months earlier.

She responded that she'd be willing to interview but needed to get all the interviews done in a day, because she was going to make a decision by Saturday, the first of May. On Tuesday, 27 April, she met with Page and Brin in their offices above a bike shop in Palo Alto. Brin, sitting next to her at the Ping-Pong table that served as a conference table, drilled her on all sorts of math and computer science theory; Page said little and seemed distracted, she recalls. "And then they got up and left, and I could hear a bunch of people piling out of the office. The office manager said, 'I'm sorry, I know it was important that we get all of your interviews done in one day, but Larry and Sergey have just gone to do a funding pitch, and the entire office has gone with them. Come back tomorrow.' "

The next day she met with Craig Silverstein, Google employee No. 1 and the company's long-time director of technology (he decamped this past February to join the Khan Academy, a nonprofit educational start-up). Mayer says he came off as one of the smartest people she'd ever met. But she thought she'd blown that interview.

Workers in downtown Palo Alto face arcane parking rules, typically having to move their cars every 2 hours from one color zone to another and being careful not to park twice in the lime zone, for

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example, on the same day. So the first thing Silverstein told her when they started the interview was that he would be testing her to see how responsible she was—in half an hour she needed to end the interview so he could move his car.

But, caught up in discussing coding problems and data storage demands, Mayer overshot the half hour by 25 or 30 percent (yes, she remembers to within 5 percent). Silverstein liked Mayer anyway (no, he doesn't remember whether or not he got a parking ticket). "We had what we called the airport test at that time," he says. "We wanted to hire people you wouldn't mind being stuck at an airport with for 4 hours. We turned down people who were qualified technically who we didn't feel fit culturally." Within days, Mayer had a job offer from Google.

Still, though, she couldn't decide. So, extending her 1 May deadline by a week, she asked an economist friend to help her. The two of them spent hours trying to graph all the factors—the salary, the stock, the lifestyle, and what Mayer calls the happiness index. Finally, at midnight, the day before her deadline, she collapsed into tears, completely overwhelmed. Her economist friend pushed aside their graphs and told her, "I'm seeing a bunch of really good options. There's going to be one that you pick and you commit to and make great. So you should sleep on it, and whatever you really want to do in the morning you should do."

WE ALL KNOW WHAT SHE DID. She was the ninth engineer hired by Google. She had no qualms about being Google's first female engineer. In fact, at the time, she didn't even realize she was. "There were other start-ups I looked at that had nearly 50 male engineers who were like, 'We really, really need you as our first woman engineer.' To me, getting to eight engineers that are all guys could be a coincidence. Getting to 50, you have a cultural problem. I definitely discarded some companies I felt didn't have a good culture for woman engineers."

She started at Google on 23 June 1999, just a week after graduating from Stanford. She immediately threw herself into trying to understand the way the search software worked and documenting the acronyms and jargon she encountered so the next new hire

Strike a Pose

Photographers can't seem to resist Marissa Mayer, here with [from top] news anchor Matt Lauer at a 2009 *Glamour* magazine event; with musician Wyclef Jean and author Meghan McCain at a *Time* magazine event in 2010; and with husband Zachary Bogue at a White House dinner in 2011.

wouldn't be quite so lost. The next week, Paul Buchheit joined the staff, and the two paired up to tackle two assignments—developing specialized search software for people looking for product information and developing software that would use people's search queries to identify and display related advertisements. They agreed that each would be the lead on one project but would review code and help as needed on the other.

Buchheit, who would go on to create Gmail a few years later, took the product-search project. Mayer took ad matching. She used Amazon.com's database of book titles and subject areas as her first data set and wrote software that would automatically classify those books into the topic categories of the Open Directory, a taxonomy of Web links administered by Netscape. The software would identify search queries related to a topic category and serve up an advertisement—in this case, a book recommendation—when appropriate. She thought that once she figured out how to do an automatic classification of books, she could expand the software to automatically classify advertisements for other products.

"We got to about an 83 percent accuracy rate in terms of classifying queries into the Open Directory. We continued for several years afterwards to have bake-offs to try to figure out if someone could build a better classifier." It was years before anyone could. Other employees hired later figured out how to display the ads selected; Mayer, meanwhile, had moved on to user-interface design. "Most of what you see on the home page and search result page, on Google News, on image search, and in part on maps, toolbar, and the icons on Chrome are things I helped with," she says with evident pride. "Even the original layout of Gmail."

That's a lot of design in a decade. "I think I was very prolific because I wasn't very trained in design. A designer maybe would have spent more time making sure the designs were really good. I just made sure the designs really worked."

THESE DAYS, as vice president of location and local services, Mayer oversees the development of the technology on which Google seems to be pinning much of its future. Indeed, pundits considered her appointment in late 2010 a sign that Google was getting serious about local services, an area dominated to date by start-ups like Groupon, Yelp, and Foursquare.

Location and local services covers Google Maps and all its features, like Street View, Transit, and Directions, the related Google Earth with satellite imagery around the globe, and Google Places,

FROM TOP: DIMITRIOS KAMBOURIS/GETTY IMAGES; NEILSON BARNARD/GETTY IMAGES; BILL O'LEARY/THE WASHINGTON POST/GETTY IMAGES

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where the company aggregates information, photos, reviews, and recommendations around specific businesses or attractions. And it encompasses just about everything, including using mobile devices, an exploding category whose growth has surprised even Mayer. At the SXSW Music and Media conference in March 2011, she effused that on Christmas and New Year's mobile usage of Google Maps had for the first time surpassed desktop usage. At the Social-Loco conference that May, she reported that there were now more mobile users than desktop users every weekend.

In the early days, most people used search engines while sitting at desks; today they search on the move. So an engine that knows a pizza-parlor search is taking place in Tokyo isn't going to suggest the array of great pizza options in New Haven, Conn. But that's just the start of what will soon become commonplace. Before long, coupon deals will pop up on your smartphone when you walk by a restaurant, search listings will be organized by the distance of the business from where you're standing, and payment systems will recognize that you're in a coffee shop and get ready for you to pay with your phone. And it's not all about commerce. Consider one of Mayer's favorite examples—the mystery bird: You see a bird and want to know what it is. You can take a picture of it, and Google's Goggles will tell you that it's a bird (but you already knew that, didn't you?). However, if your device knows where you are, it can narrow its search down to birds that frequent the area, making identification that much simpler.

Since Mayer took over location and local services, the organization has steadily rolled out new technology. Hotpot, released in late 2010, personalizes search by allowing people to share recommendations with friends and also use their own reviews to tailor results; it has since been rolled into Google Places. There's the Art Project, unveiled in early 2011, which used Street View—the application that allows users to take a virtual walk down public streets and look around as they go—to put 17 museums into cyberspace so online visitors can tour them virtually. It's not a coincidence that Mayer is an avid museumgoer who's on the boards of the San Francisco Museum of Modern Art and the Smithsonian Cooper-Hewitt, National Design Museum, in New York City. Google Business Photos, which takes Street View into private companies, started with a test group last year; this January, it was opened to all small businesses. And last fall Google purchased Zagat, the popular restaurant rater, which Mayer announced would serve as a cornerstone for Google's local offerings.

Mayer's personality is likely to influence the evolution of Google's local services in subtle ways. Whenever she speaks publicly about the possibilities of geographically aware technology, she gushes not about how advanced it all is but about how efficient it can make users—and how that efficiency will save them time to do interesting things.

BECAUSE FOR MAYER, it's not just about technology. It's about having fun, too. She personally supervises the choice of holiday doodles for the Google home page—she decides what holidays, artists, and milestones will be honored and when. She does the art direction and approves the designs. She's also had her hand in other aesthetic choices, including, famously, the standardization of Google blue. Three years ago, *The New York Times* reported that she asked her team to test 41 shades of blue before settling on a color.

Says former colleague Buchheit, "Her design aesthetic—an interest in Scandinavian style but with a lot of bright colors—matches nicely with what is Google design."

And Mayer likes to share her fun. Within her first month or so at Google, she convinced some of the other employees to join her and George Harik, now founder of a nonprofit artificial intelligence laboratory, at a Friday night movie. That quickly became a tradition. When the company outgrew its Palo Alto offices and moved to its current Mountain View campus, conveniently near a multiplex, the movie outings grew from a dozen or so people to 50, and then 80. Mayer would take a head count and personally run over and buy tickets during lunch. When *Star Wars: Episode II* came out in 2002, she bought out an entire showing. By *Spider-Man 2* in 2004, Google bought 18 000 tickets for showings that ran throughout the opening Friday.

While organizing movie outings and picking holiday doodles may seem a bit of a stretch for a geek gal, they grow out of genuine passions. She loves movies—so much so that her Palo Alto home contains a miniature theater, decorated with posters of some of her favorite films and complete with candy counter and popcorn machine. She decorates that house lavishly for holidays. Even her 2009 wedding had a holiday theme, with Christmas decorations and the singing of "Silent Night."

On a typical day she works from 9 a.m. until 7 or 8 p.m, usually commuting from Palo Alto; she and her husband also have a condo at the Four Seasons Hotel in San Francisco, which they use mostly on weekends. Twice a week she works late, which she defines as around midnight. She also teaches introductory computer programming at Stanford and mentors students at the East Palo Alto Charter School. She eats most of her meals on the Google campus and she does a lot of her shopping at work, ordering clothes online, having them shipped to the office, and trying them on in the bathroom.

It helps that she doesn't need much sleep. Recalls Google's Silverstein, "I met her once at dinner in New York; she was literally falling asleep in her soup. She said, 'Normally, I can get by on 4 hours of sleep a night, and I thought I could get by on 3. But I can't.' "

Though estimated to be worth several hundred million dollars, Mayer still comes off as the coed who blanched at the cost of a Stanford premed education. She'll even think twice about taking a cab if her destination is within walking distance. Her restaurant picks tend to be as much about great value as the food—visiting New York, she's more likely to eat at La Bonne Soupe than at Per Se. And though she drives a BMW, it's 17 years old.

Is this engineer/girly girl/ultra exec simply a bundle of contradictions? Absolutely not, says Andre Vanier, a friend since their days as Stanford undergrads. In fact, he says, she's actually a perfect match for Google. "Yes, she's left-brained and right-brained in a way that is unusual—a talented ballerina in her student days, now a computer science business success. But the company is also left-brained and right-brained, with hard-core analytics along with ways to make the search experience fun. Marissa helped shape Google, and Google encapsulates Marissa's personality." ❑

POST YOUR COMMENTS *online at* http://spectrum.ieee.org/mayer0412

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THE RELAY REBORN

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A TRUSTED OLD TECHNOLOGY—THE ELECTROMECHANICAL SWITCH—COULD PAVE THE WAY FOR ULTRALOW-POWER CIRCUITS

By Tsu-Jae King Liu,
Dejan Marković,
Vladimir Stojanović
& Elad Alon

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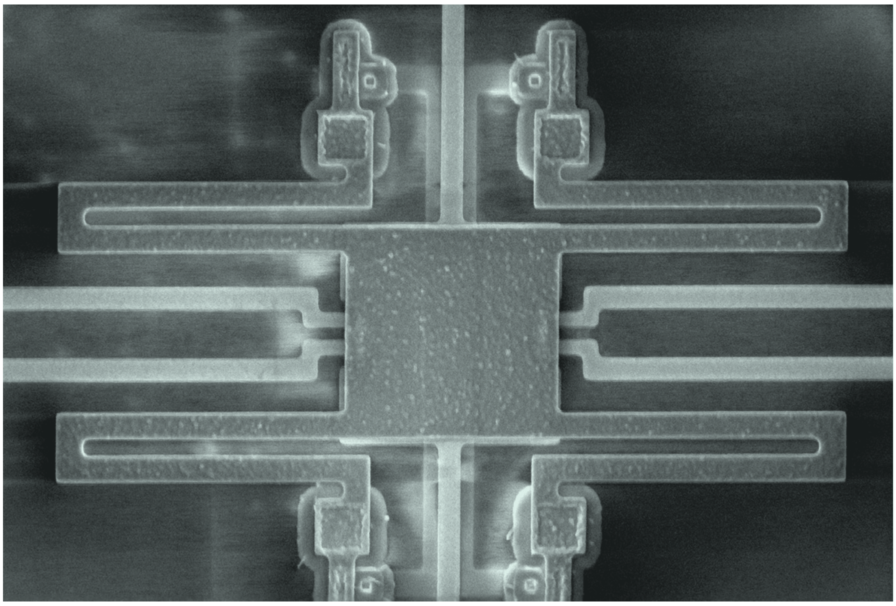

MECHANICAL LOGIC: This six-terminal relay, which boasts a 7.5-square-micrometer gate, and the larger four-terminal relay [previous page] are built so their gates and channels hover above the rest of the switch. PHOTO, LEFT: SEMATECH; PREVIOUS PAGES: UC BERKELEY

The integrated circuit has made such steady strides over the past 40 years that it's easy to believe in a sort of "manifest destiny" for electronics. How could a year go by without the introduction of cool new gadgets boasting previously unimagined capabilities at amazingly affordable prices?

But the chip industry is approaching a crisis. After decades of progress, continued improvement in power efficiency has begun to stall. If we want to continue proliferating cheaper, smaller electronics and usher in what many in the chip industry call an Internet of Things—a future full of billions of always-on, always-connected devices and sensors—we will have to look beyond the CMOS transistor to find a less power-hungry technology.

The future may lie in the past: Looking back to the earliest days of electrically driven computing, we've found a surprisingly attractive alternative. It's the electromechanical relay. As a switch, the relay is about as fundamental as you can get—it uses a voltage to physically open and close a circuit. Early relays were far too slow and power hungry to compete with vacuum tubes, let alone transistors. But by using modern CMOS production processes, we think the relay can get a microscopic makeover.

These miniature moving switches—or nanorelays—aren't as speedy as the solid-state devices on today's chips. But what the tiny mechanical switches lack in speed they make up for in energy efficiency. Nanorelays don't leak current when they're off, and they can change states with just a fraction of the energy that's needed to turn a transistor on or off. These qualities make the microscopic switches ideal for ultralow-power chips that can run off scavenged energy from acoustic vibrations, light, or ambient radio signals. With some clever engineering, it may even be possible to make nanorelays fast enough to drive the core logic inside cellphones, tablets, and other portable electronic devices.

Mass-produced chips full of moving parts aren't as far off as they might seem. After years of small-scale experiments, we're now on the cusp of demonstrating fully functional, complex integrated circuits that are entirely mechanical. The long-retired relay could soon be reborn.

For decades, every time engineers reduced the size of the transistor, they were rewarded with a faster and more energy-efficient switch. But a little more than a decade ago, chipmakers realized that simply shrinking transistors wouldn't improve their energy efficiency the way it used to.

The problem is that transistors are imperfect switches; they leak current even when they're supposed to be shut off. This leakage is fundamental to the way the transistor operates, and so there's no easy way to eliminate its effects. If you reduce the operating voltage of the transistor, less energy will be needed to switch the device. But the amount of time that this lower-power transistor takes to switch will balloon, and meanwhile the other transistors in the circuit will leak more current while they're waiting for the operation to be completed. As a result, there's a fundamental limit to the energy efficiency of a CMOS circuit, and we're fast approaching a point where we won't be able to keep boosting the performance of a chip without increasing power consumption.

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The good news is that you can avoid leakage altogether if you use a switch that simply lacks a pathway for electricity to flow through when it's off. An early model of such a switch—the relay—was invented in 1835 by the American scientist Joseph Henry, right around the same time that Charles Babbage was devising steam-powered calculators. Henry's first relay used induction to power up an electromagnet, which would tug on an armature that mechanically closed a gap between two electrodes.

The relay cleared the way for the first complex, programmable computers—machines that could compute logarithmic tables or analyze aerodynamic forces—in the late 19th and early 20th centuries. The very first general-purpose, electrically powered digital computer, Germany's Zuse Z3, unveiled in 1941, used about 2000 relays to perform calculations for aircraft design.

But the relay's role in computing was short-lived. The Z3, which boasted clock speeds of less than a dozen hertz, was quickly surpassed by computers based on the vacuum tube and later the transistor. The relay is about to come full circle though: Decades of advances in lithography, etching, and other techniques used to fabricate CMOS chips now offer us the means to revive relays in a smaller, more energy-efficient form.

As you might imagine, there are plenty of ways to go about designing a miniature mechanical switch. You could, for example, reproduce the classic relay on a much smaller scale by using current to physically push or pull on a tiny piece of magnetic material. And indeed, researchers have done just that. In 2001, a team at Arizona State University showed that a cantilever made of an iron nickel alloy could be drawn down to complete a circuit by running current through a nearby coil. This device wasn't compact and energy efficient enough to be practical for large-scale integration, but it created enough interest among researchers that they began exploring other ways to shrink the relay.

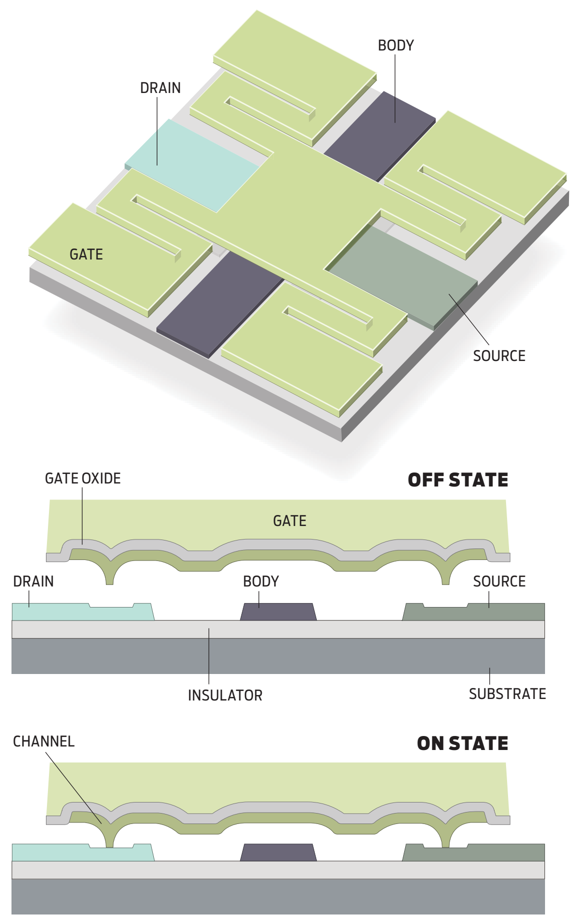
Since then, others have devised relays that derive their mechanical motion from thermal expansion or from piezoelectricity, a property of some materials to expand or contract under the influence of an electric field. These designs have shown great promise, but the approach that seems to be most compatible with existing chip production processes—and most capable of scaling down to sizes comparable to those of today's transistors—is the electrostatic switch.

At the University of California, Berkeley, we've been working on such a switch: a micrometer-scale relay inspired by the CMOS transistor. Like a transistor, the relay contains a source, a drain, and a channel through which current flows, as well as gate and body electrodes that control the device's state. But the relay boasts a key structural difference: The gate and channel are suspended above the source and drain rather than built alongside them.

We achieved this configuration by etching the gate—which consists of a square and four springy suspension coils attached at the corners—out of a conductive silicon germanium alloy. Because we cleared away some of the intervening material during the device fabrication process, the gate is suspended less than 100 nanometers above the "base" of the switch. This base is divided into three parts—a "body" electrode that serves as a reference potential for the gate, and source and drain electrodes located on either side of the body electrode. Attached to the insulated underbelly of the gate is a layer of conductive material that forms the channel.

If the voltage difference between the gate electrode and the body electrode is sufficiently large, then the electrostatic attraction between the opposite charges on the gate and body exerts a force that pulls the gate down. This stretches the springy coils and brings the channel into contact with the source and drain electrodes so that it forms a conductive bridge for current to flow through. When the applied voltage between the gate and the body is lowered, the electrostatic force is reduced and eventually becomes lower than the restoring force of the coils. The gate is then pulled back to a neutral position so that it's once again suspended above the body of the switch. In that state, an air gap separates the channel from the source and drain electrodes, preventing current from flowing.

SPRING POWER: Springy suspension coils are used to anchor the nanorelay gate and channel. A sufficiently strong voltage difference will draw the gate stack down and let current flow.



GEORGE RETSECK

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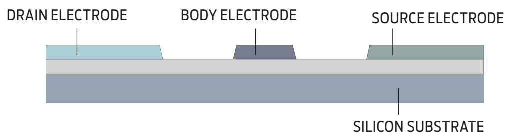
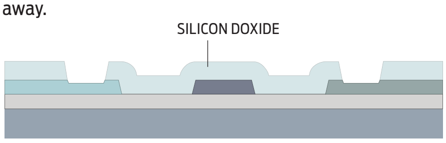
NANO FAB: Nanorelays can be built using processes that were originally developed to make CMOS chips.

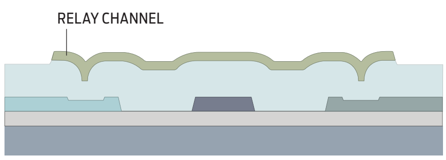
Construction begins with the source, drain, and body electrodes, which are built by depositing a metallic material like tungsten on top of an electrically insulating layer.



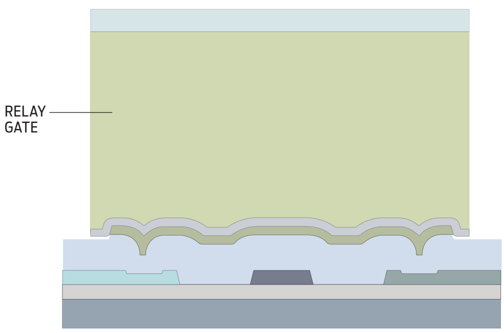
A layer of removable, sacrificial material like silicon dioxide is added to form the foundation of the moving part of the switch. The spots where the channel will make contact with the source and drain electrodes are etched away.



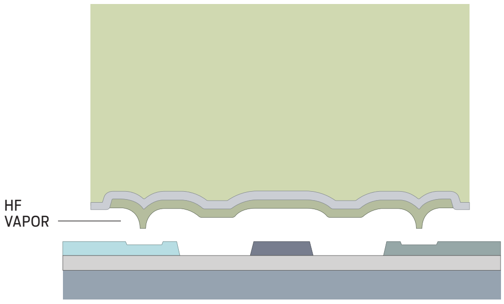
A second layer of sacrificial material is deposited to create a contoured surface. A metallic layer is then added to form the relay channel, its lowest points aligned with the source and drain electrodes.



Another insulating layer is added to electrically isolate the channel from the next layer in the moving stack—the relay gate. This is built from a thick layer of semiconducting material, which is also used to form the springlike parts of the structure. An insulating layer on top protects the gate and the springy coils as unneeded material is etched away.



Hydrofluoric acidic vapor is used to clear away the sacrificial material, leaving an air gap between the channel and the base of the switch.



The resulting relays aren't particularly speedy compared to today's transistors. A relay that's about the size of a modern CMOS device can take anywhere from 1 to 10 nanoseconds to mechanically switch—100 to 1000 times as long as the typical limiting factor in the speed of a transistor-based circuit, the time needed to electrically charge or discharge an output signal. Because of this, if you were to take an optimally designed CMOS circuit and simply substitute a relay for each transistor, you'd wind up with a perfectly functional relay circuit but one that's less than a hundredth as fast as your original circuit.

Fortunately, our research team—which includes members at Berkeley, UCLA, and MIT—has demonstrated that the effect of this long mechanical delay can be minimized by optimizing the circuit design. In a CMOS circuit like an adder or multiplier, the transistors are typically arranged in small groups to make fairly simple logic gates. Each of these gates contains a handful of transistors and operates in sequential order—the output of one gate is used to influence the state of the next gate. This approach ends up being speedier than building more-complex logic gates out of large collections of transistors connected in series or in parallel.

It turns out that the best way to design a digital relay circuit block is to take a page from the first half of the 20th century, when large discrete relays were still used to build computers. Instead of grouping the nanorelays into discrete simple gates, as you would do with transistors, the best approach is to arrange many of them in series and in parallel to make as few gates as possible. If all the devices can be arranged into one single gate, all the nanorelays can be switched simultaneously, and the time required to perform any function is reduced to a single mechanical delay.

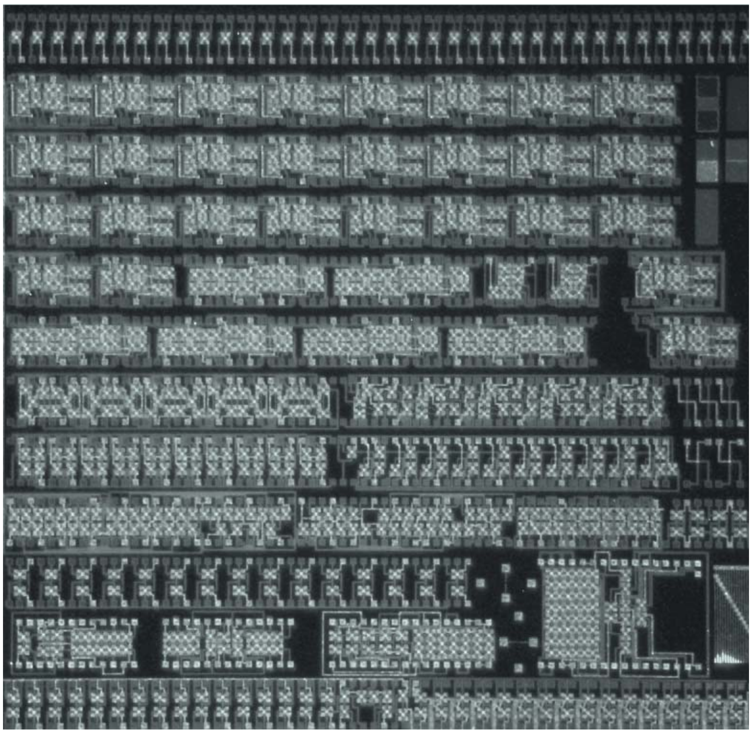
This approach works because the extra delay associated with the movement of electrical signals through more-complex circuits remains minuscule compared to the mechanical delay associated with opening or closing a single switch. When combined with other relay features, logic circuits built this way require fewer devices, saving space and thus chip cost. While a CMOS adder might require 25 or so transistors, we've built nanorelay adders that need only 12 switches. The mechanical circuits that have been fabricated to date contain relays that are micrometer-size, dozens of times as big as today's highest-performance transistors. But our research—as well as studies by teams at Stanford and Caltech—indicates that relays can be shrunk in a way that's similar to what's been done for CMOS transistors, and with similar gains in performance.

Extrapolating from our current relays, our simulation results indicate that for the same lithographic dimensions, a nanorelay circuit could consume as little as a hundredth of the energy while occupying the same chip area as that of an equivalent CMOS circuit. We estimate that nanorelay circuits made using mature 90-nm chip technology could operate at speeds up to about 100 megahertz.

In these days of multiple-gigahertz processors, it might seem strange to contemplate an entirely new technology that's capable of only about a tenth of the speed. But that amount of computing power is more than enough to drive the logic behind the various sensors, cameras, implanted electronics, and communication devices that will form the future Internet of Things.

And as the nanorelays get smaller, both their energy efficiency and their speed will continue to improve, potentially

GEORGE RETSECK



CLICK, CLACK: This 9- by 9-millimeter relay test chip, built at the University of California, Berkeley, contains a 100-relay multiplier [fourth row from bottom], designed by MIT researchers, that is the largest relay integrated circuit demonstrated to date.

up to speeds of a gigahertz or so. The best way to boost the speed will be to reduce the mechanical delay of the relays. We could, for example, make the relay's gate and channel out of lighter materials so that the switch will accelerate faster for a given force. We could also build the relay so that the gate is suspended closer to the body of the switch, reducing the distance a nanorelay gate must travel between its on and off states and boosting the attractive force between the electrodes.

IT ALL SOUNDS STRAIGHTFORWARD ENOUGH, but we'd be remiss if we didn't mention a couple of caveats. One question we're often asked is: What would happen to a relay chip if you dropped it? Probably nothing. It turns out that the mass of the movable electrode in a nanorelay would be so small—on the order of a billionth of a gram—that accelerations in excess of 100 000 *g*s would be required to overcome the restoring force on the movable electrode springs and cause the channel to accidentally come into contact with the source and drain. To put this number into context, dropping your cellphone on the ground typically results in less than 1000 *g*s of acceleration at the moment of impact. Thus it is extremely unlikely that vibrations and mechanical shock would cause a relay chip to fail, let alone damage it—unless your phone happens to explode into pieces.

Another issue is reliability. Any mechanical device will eventually wear out or break with repeated use. In the case of the nanorelay, the most likely way the device will break down is through the contacts—the spots where the channel comes into contact with the source and the drain. The heat created as these contacts conduct current to charge or discharge the output of the relay can eventually cause the contacts to become welded together or even to vaporize.

Conveniently, though, the relative sluggishness of the nanorelay lets us use materials that are more resistant to wear. The electrical delay associated with charging and discharging a switch when a channel comes into contact with or is lifted off the source and drain is tiny compared to the mechanical switching time. As a result, we are free to use more wear- and heat-resistant materials like tungsten for the contacts. Such hard materials don't make good electrical contacts—they don't deform when pressed into one another, so actual contact is usually made at only a few points. The resulting small contact area increases the electrical delay, but that delay is still small compared to the mechanical delay.

Extrapolating from the amount of wear seen in our experiments, we estimate that nanorelays could be used to make a practical microcontroller for an embedded sensor that switches a quadrillion (10^{15}) times without failing. That level of activity corresponds to running 1 percent of the time at speeds of 100 MHz for 10 years.

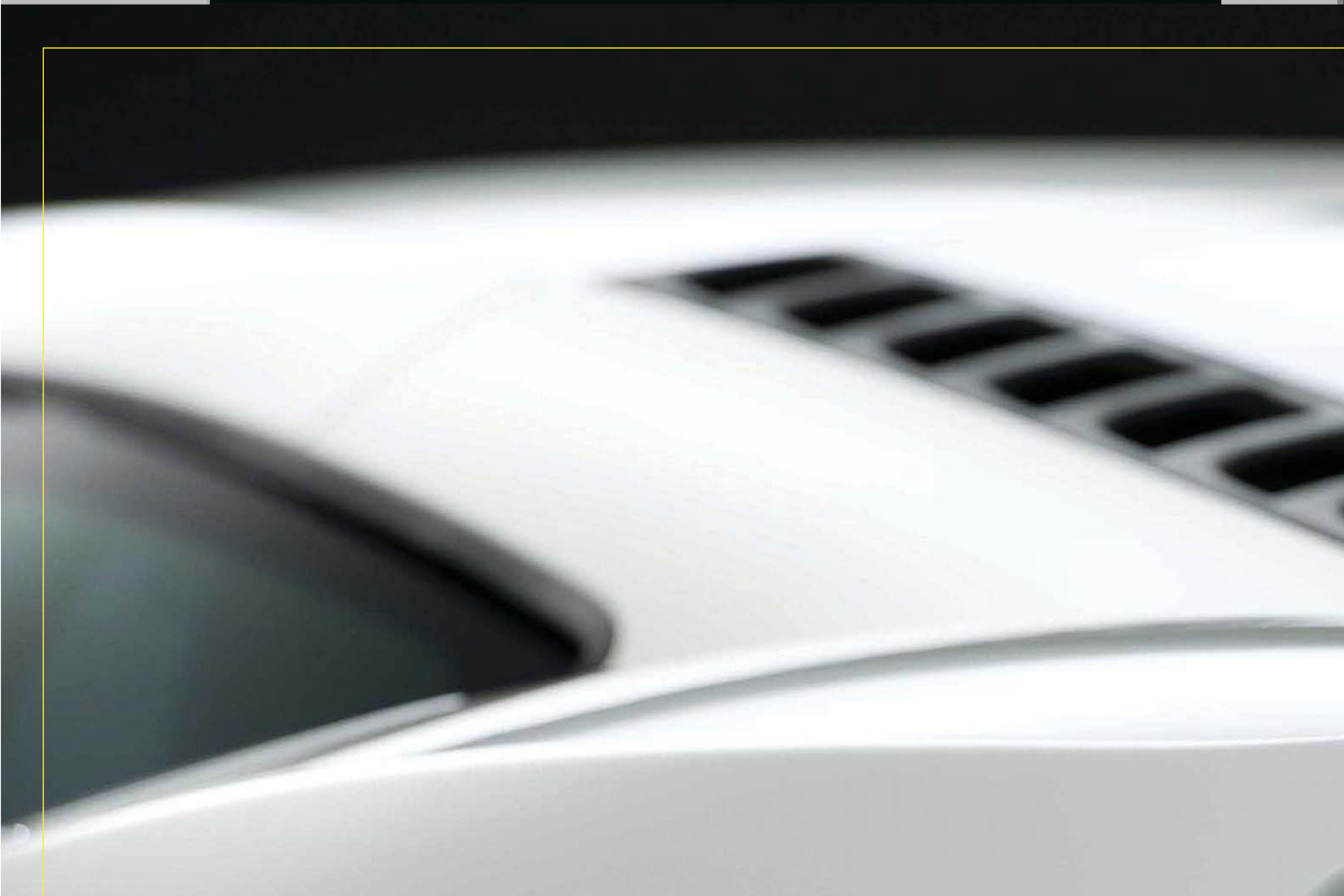
Furthermore, we expect that as relays are scaled down, they'll likely become even more reliable. One key reason is that smaller relays will have lower capacitance, which means it will take less time for components to charge or discharge. That will reduce the amount of heat that's dissipated through the contacts.

Before relays can become the next mainstream integrated circuit technology, two critical things still need to happen: The relays need to get smaller, and they need to be fabricated into more-complex circuits. A number of teams are working on both tasks. We've already shown that memory, as well as basic logic circuits such as adders and multipliers, can be built with nanorelays. The next step is to build full chips like microcontrollers, which would easily contain thousands or even millions of switches. In the process, we'll develop techniques to optimize the design of very-large-scale integrated circuits and also get the wafer fabrication chain ready for those large chip designs.

Fortunately, creating integrated circuits containing millions or even billions of these nanorelays should be relatively uncomplicated. Apart from some relay-specific design rules, checks, and device models, we've been able to use the same computer-assisted design tools developed for the silicon CMOS industry to place and route relays and simulate circuit behavior. Being able to reuse this software is critical, because rebuilding this infrastructure from scratch would be very expensive.

Much work remains to be done, of course, but nanorelay technology appears to have the potential to break through the CMOS energy-efficiency roadblock and restore the manifest destiny of electronics. Before long, we may see cool new devices that operate for weeks or years on a single battery charge. All it will take is for a few million things to click into place. ❑

POST YOUR COMMENTS *online at* http://spectrum.ieee.org/nanorelays0412



2012 TOP 10 TECH CARS

The Internal Combustion Engine Strikes Back

BY LAWRENCE ULRICH

WHEN PEOPLE DREAM ABOUT the future of driving, they picture hundreds of millions of cars humming almost imperceptibly on batteries or fuel cells, their power plants emitting water vapor or nothing. Rarely does petroleum fuel—and foul—the green fantasy.

But don't let that vision distract you from reality. Although the world's biggest automakers are determined to bring electrified cars to the masses, their real business—and the world's business—will continue to revolve around the internal combustion engine for decades to come. The signs are accumulating: Morgan Stanley now projects that just 4.5 percent of new cars sold in 2025 will be EVs, sharply down from its previous estimate of 8.6 percent.

Yet change is afoot, change that heralds the remaking of the invention that first began to put the world on wheels about 120 years ago. Most notable over the past year has been the remarkable rise of the turbocharger, as makers from Motown to Munich have begun adopting turbocharging and even supercharging to radically downsize engines, boost fuel economy, and cut pollution—usually without sacrificing anything in power or drivability.

This year's list shows turbocharging up and down the line, from a Japanese hatchback to a British supercar. Of course, the list has a few EVs and hybrids also; as always, our emphasis is on interesting new technology, not just the market share that it commands for now. ❑

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McLaren MP4-12C

Now with carbon fiber!

AS I COAX THE MCLAREN MP4-12C eastward along Route 301 in New York's Hudson Valley, the tall gates of the Chuang Yen monastery loom, then disappear in a flash. To the monks inside, I'm a silvery, shrieking blur.

They might not agree (and I'm sorry if I busted up their meditation), but the McLaren's essential nature rings in tune with this Buddhist temple. For all its Formula One credentials, for all its flashy virility and hair-trigger handling, the McLaren also sets a new supercar standard for inner peace.

For the MP4-12C, McLaren refused to accept traditional trade-offs between performance and comfort, and that's what makes this model the year's most intriguing new sports car. The company owes its achievement—and its position in this year's Top 10 list—to its democratization of a weight-saving technology that had been limited to the ultrarich: carbon-fiber construction.

Here "democratization" means that it's now affordable for the merely rich. The starting price of US $231 400 is by far the lowest of any car ever draped on a carbon-fiber structure. And while you could buy 10 Hyundai Sonatas for that price, recent breakthroughs have McLaren—along with mega-automakers such as BMW—confident that large carbon-fiber components will eventually trickle down to mass-market cars.

McLaren's bona fides here are unmatched. The company built and raced the first carbon-fiber Formula One monocoque back in 1981. Every McLaren since has been carbon-fiber intensive, including the MP4/4 racers driven by Ayrton Senna and Alain Prost, which won an unparalleled 15 of 16 Formula One races in 1988. By 1992, the legendary three-seat, $1 million McLaren F1 became the first road-going car with a carbon-based chassis.

Until recently, woven sheets of carbon fiber had to be laid up by hand in a mold, impregnated with resin, then cured for hours in an autoclave oven. It was a black art. Back in 1992, building just the F1's "tub," which surrounds the driver, took 3000 hours. By 2004, the Mercedes-Benz SLR McLaren had chopped that to 400 hours.

For the MP4-12C, McLaren adapted a process called resin transfer molding, which cuts fabrication time by 99 percent. Bundled fibers are stuffed into a huge mold, epoxy resin is injected, and heat and pressure do the rest. The one-piece tub, called a MonoCell, takes a mere 4 hours to build and weighs 75 kilograms, less than many passengers.

Such strong, lightweight bones are key to the new car's remarkable structural rigidity and agile yet compliant suspension. The entire car weighs 1301 kg, nearly 80 kg less than its main competitor, the Ferrari 458 Italia. The hollow carbon structure forms a "safety survival cell" akin to that of an F1 car, with aluminum crumple zones in front and in the rear that are easy to replace.

That light weight also means low emissions: The McLaren produces less than 300 grams of carbon dioxide per kilometer driven, topping its class. Because the shell resists twisting so well, the suspension can be optimized to provide the best possible ride and handling. And carbon fiber is more resistant to fatigue than metal. So the McLaren will, in theory anyway, feel as tight and new in 10 years as it does the day it leaves the showroom.

ALL PHOTOS PROVIDED BY MANUFACTURERS

2012 MCLAREN MP4-12C
ENGINE: 3.8-L twin-turbocharged V-8, 441 kW (592 hp)
BASE PRICE: US $231 400

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A compact 441-kilowatt (592-horsepower), twin-turbocharged 3.8-liter V-8 lies smack dab in the car's center of gravity. Add a seamless seven-speed, dual-clutch automated manual transmission and the McLaren casually puts up supercar numbers: 0 to 97 kilometers per hour (0 to 60 miles per hour) in 3 seconds and a top speed of 330 km/h (205 mph).

Dihedral doors do without old-fashioned door handles: Sweep a hand along a sensor and the doors pivot upward with one-finger ease; the doors open less widely than conventional ones.

The cockpit is designed for a fast driver and a stupefied passenger, not for downloading reruns of "The Office." There's not a single button on the steering wheel, which is flanked by a pair of paddle shifters, whose action is a little stiff for my taste; McLaren says an adjustment may be in the works.

Yet although interfaces are simple, the technology below is anything but. And the tour de force is the ProActive Chassis Control system, which does away with conventional shock absorbers and heavy antiroll bars.

Instead, the McLaren's body motions and ride stiffness are controlled entirely through hydraulics, within a series of linked, pressurized cylinders at each corner of the vehicle. Imagine water being sloshed around the floor of a boat as it heaves and pitches and you'll have an idea of how it works.

The system works by sending fluid from front to back or from side to side, in a fraction of a second. Set the system to Normal and the McLaren trundles over potholes as obligingly as a luxury sport sedan. And unlike some cars with adaptive systems, the McLaren undergoes a serious Jekyll-to-Hyde personality change when you crank up its settings: In Track mode, body-roll stiffness is doubled, gearshifts are eye-blink fast, and the special Aero mode lifts the rear wing slightly for increased downforce at exhilarating speeds. That wing also acts as an air brake, shooting upward to clamp down the rear under hard braking, countering the car's forward weight shift to allow the rear brakes to apply a greater share of force.

From public roads in New York to a twisty racing circuit in Fontana, Calif., the McLaren made a convincing case for inclusion in any supercar smackdown: Its body stayed almost eerily flat at speeds that would have had a Porsche 911 leaning over and its tires howling.

This may seem strange to say of a car that only the select few can possibly afford, but the MP4-12C is a wonderful deal: It delivers seven-figure technology at a six-figure price. ❑

WHITE OF WING: **The McLaren's dihedral doors enfold just two people—a fast driver and a stupefied passenger—and not a single button defaces the elegant simplicity of the steering wheel.**

AUDI A7

A supercharger, a 15-speaker stereo, and Google Earth as a copilot

AUTO EXECUTIVES, especially when plied with single-malt scotch whisky, love to talk about the "package"—the integration of design, technology, safety, and performance into a satisfying whole.

But today few carmakers are delivering the complete package like Audi. The A7, the year's showstopping "four-door coupe," is the latest example of why Audi is on a roll.

First, the car looks lovely. From its freight-train grille to its swoopy tail, the A7 isn't bland. You won't gas it up or make it through the grocery parking lot without getting a compliment. The ego stroke continues inside: Check out those Bang & Olufsen tweeters—part of a 1300-watt, 15-speaker system—that rise from the dashboard like sprinklers on a country club's fairway.

But as with Apple's top products, the Audi's slick packaging enhances its user friendliness. The A7's hatchback is smoothly integrated, avoiding the hunchbacked proportions of the Porsche Panamera.

ENGINE: **3.0-L supercharged V-6, 231 kW (310 hp)**
BASE PRICE: **US $60 125**

The Audi's 3.0-liter supercharged V-6, aided by a terrific eight-speed automatic transmission, is another leading avatar of the downsizing trend. Generating 231 kilowatts (310 horsepower) and 441 newton meters (325 foot-pounds) of torque, the engine combines a ripping 5.4-second run from 0 to 97 kilometers per hour (0 to 60 miles per hour) with class-leading economy of 13.1 liters per 100 kilometers (18 miles per gallon) in the city and 8.4 L/100 km (28 mpg) on the highway. Audi has preferred turbos in recent years, but it claims that in this application, supercharging—which drives an engine-boosting compressor with an engine belt rather than a turbo's exhaust gases—delivers not just an instant power boost but also great fuel economy.

For an extra US $25 to $30 a month (after the first six months, which are free), the new Audi Connect offers an industry-first Google Earth–enabled navigation system. The gadgetry continues with radar-based adaptive cruise control, a color head-up display, blind-spot and lane-departure monitors, and a system that detects an impending crash and warns the driver before automatically stopping the car. Its Night Vision Assistant highlights the silhouettes of pedestrians on a display screen. The Drive Select system lets drivers toggle through four settings to adjust the steering boost, transmission shift points, and throttle sensitivity.

If there's a nagging issue with the A7, it's the price: $60 125, or nearly $10 000 more than that of the A6 sedan, a sister model that's essentially the same car, minus the sleek hatchback body. But such is the price of high style at Audi.

MERCEDES-BENZ E300 BLUETEC HYBRID

At last, a diesel hybrid

ENGINEERS HAVE LONG VIEWED diesel and hybrid technology as a potentially sweet combination. But it's hard to mate the two costly systems in one car.

Now Mercedes claims to have done it: The E300 BlueTec hybrid sedan goes on sale in Europe in the second half of this year; around the same time, its modular hybrid system will find its way to North America in gasoline form, in the V-6-powered E400 BlueTec sedan.

Mercedes unveiled both cars at Detroit's annual auto show in January. And in contrast to hybrids and electric vehicles with pricey, space-hogging battery packs, the Mercedes system crams its entire hybrid module—including a tiny, 0.8-kilowatt-hour lithium-ion battery—into the engine compartment. There's no intrusion into the passenger compartment or the trunk space, and the hybrid components add only 100 kilograms to this 1780-kg midsize sedan.

ENGINE: 2.1-L turbo diesel, 150 kW (201 hp), plus a 20-kW electric motor
BASE PRICE: Not yet announced

In both cars, a small electric motor is sandwiched between the engine and the seven-speed automatic transmission. That motor contributes 20 kilowatts (27 horsepower) and 250 newton meters (184 foot-pounds) of torque—enough oomph to run the Benz entirely on electricity from a standing start.

For the E300, a 2.1-liter turbo diesel delivers 150 kW (201 hp) and a fat 500 Nm (369 ft-lb) of torque. (The U.S. E400 will go with a 3.5-liter gasoline V-6 with 50 percent more power and more than 35 percent more torque.)

The result is an E-Class sedan that consumes just 4.2 liters of diesel every 100 kilometers, or gets 56 miles per gallon in combined city and highway economy on the European test cycle. The BlueTec sedan also emits 109 grams of carbon dioxide per kilometer, comfortably below the European Union's 2015 target of 130 g/km.

Diesels already have great low-end torque, so here the electric assistance helps by letting the diesel stay in its most efficient range, typically well under 2000 revolutions per minute.

And like the Porsche Cayenne S Hybrid, the Mercedes has an added electrically operated clutch that allows the engine to be shut off and entirely decoupled from the wheels. That lets the Mercedes "sail," or coast, even on only very slight downhill grades, at up to 160 kilometers per hour, using no fuel—another way to help owners sail past the pump.

Mazda CX-5

The highest compression of any gasoline engine around

THE WORLD'S HIGHEST-COMPRESSION gasoline engine in a production car? You won't find it on a million-dollar supercar but on a sporty grocery-getter from Japan. The new CX-5 crossover, outfitted with Mazda's Skyactiv, a new technology suite for engine, chassis, transmission, and aerodynamics, also happens to achieve 6.7 liters per 100 kilometers (35 miles per gallon) on the highway. That's the best mileage of any nonhybrid compact crossover SUV sold in the United States.

In the CX-5, the 2.0-liter Skyactiv-G engine develops 116 kilowatts (155 horsepower). It also incorporates a trick exhaust manifold that helps the engine achieve up to a 14:1 compression ratio on Europe's premium fuel. (The engine runs just fine on 87 octane, the standard U.S. fuel.)

Engineers have long known that boosting an engine's compression ratio can improve thermal efficiency. But cranking up cylinder pressure

2013 MAZDA CX-5
ENGINE: 2.0-L four-cylinder, 116 kW (155 hp)
BASE PRICE: US $21 490

raises the temperature, causing premature combustion—better known as engine knock. To avoid knocking and potential damage, Mazda cools the air/fuel mixture with a freer-flowing exhaust system, which reduces the amount of hot residual gas inside the cylinders after combustion. To ensure efficient combustion, a fuel injector squirts a fuel-air mixture directly into the cylinder (rather than into a manifold upstream, as in some other systems) through multiple holes in the cylinder wall. Such direct injection—under a pressure of 204 kilograms per square centimeter (2900 pounds per square inch)—fills the chamber very evenly, so the mixture can burn efficiently. A special cavity in the pistons—picture the hole atop a volcano—shapes the burn, accelerating combustion speed. Together, all these tricks boost both power and fuel economy by roughly 15 percent over a conventional engine, without the high costs of hybrid or diesel technology.

And a slick new six-speed automatic combines the best features of conventional automatics and today's automated manual units: For smooth takeoffs, it sends power through a typical fluid torque converter; at speeds beyond 8 km per hour (5 miles per hour) a mechanical clutch steps in to provide notably direct, snappy shifts. Throw in a marvelously tuned steering and suspension and the CX-5 delivers the entertaining handling that's become a Mazda trademark, albeit with only modest acceleration. And the entire package starts at just US $21 490, making the Mazda's smart tech an especially bright buy. ❑

SIMPLE BUT SATISFYING: **The CX-5 looks like a crossover SUV, but its handling is lively and its fuel economy superb.**

2012 BMW 528i

ENGINE: 2.0-L turbocharged four-cylinder, 179 kW (240 hp)

BASE PRICE: US $47 575

BMW 528i

Exhausting itself on a new kind of turbocharger

A HIGH-PERFORMANCE, midsize BMW sports sedan with a four-cylinder engine? What next—a laptop with a 16-bit microprocessor? A Shetland pony running the Kentucky Derby?

That was the gist of my reaction when I first heard the details about the 2012 BMW 528i. And then I drove it. Now I'm a believer.

Plenty of other automakers have mated a four-banger with a turbocharger. Audi, Subaru, and Ford all offer them; even the late, lamented Saab had them for years. But nobody has ever managed to do what BMW has: Its new TwinPower engine, also known as the N20, is so powerful and responsive that only a rank sentimentalist would miss the six-cylinder. No wonder it just became the first four-cylinder engine BMW has offered in the United States since 1999.

The N20 wrings more performance out of less volume and weight than the naturally aspirated, six-cylinder engine it was designed to replace. That's just what it has to do, given the challenge posed by electric-drive technology. Besides the 528i, two other BMW models have already adopted the engine: BMW's signature best seller, the redesigned 2013 3 Series, and the Z4 sDrive 28i convertible.

This is a wrenching upheaval in the Bavarian Bauhaus. It's the motoring world's *All About Eve*, with the N20 as the sneaky, talented ingénue who's dethroned the perennial star—BMW's venerable in-line six. If that sounds like a tearjerker to you, dry your eyes and read on. This engine displaces 2 liters and weighs 16 kilograms less than the engine it replaces.

But with turbocharging, BMW's Valvetronic variable timing system and direct fuel injection, this little marvel pumps out 179 kilowatts (240 horsepower) and 352 newton meters (260 foot-pounds) of torque—54 Nm more than the in-line six can provide.

Like any turbocharger, the TwinPower forces air into the combustion chamber with a pump powered by a turbine spinning in the exhaust stream, rather than allowing the air to be sucked in naturally by the motion of the piston. That conventional turbine method, however, traditionally suffers from "turbo lag," a delay in power while the turbine spools up to optimal speed.

To overcome this lag, some carmakers substitute two smaller turbochargers for a single large one. BMW goes them one better with its "twin-scroll" design. Instead of having every cylinder dump exhaust into a single turbine path, this design gathers the flow from pairs of cylinders into separate channels, or scrolls. That reduces the interference that comes as irregular pulses of exhaust gas strike the turbine blades. Less interference means less kinetic energy wasted and nearly instantaneous turbo response.

The design makes possible a seeming thermodynamic impossibility: an increase in both power and efficiency. The engine produces maximum torque at just 1250 revolutions per minute, compared with 2750 rpm for the old six-cylinder. Yet the engine gets you 15 percent farther on a tank of gas (and if you opt for BMW's new eight-speed automatic transmission, you'll go 20 percent farther).

I drove a 528i from Orange County, Calif., to Santa Barbara, racking up an impressive 6.7 liters per 100 kilometers (35 miles per gallon) on the highway. BMW, unlike many luxury rivals, is keeping the stick-shift faith, and I found that the six-speed manual shifter makes the most of the engine's flexible power. (When the engine is strapped into the slightly smaller 328i, BMW expects it to achieve 9.8 L/100 km (24 mpg) in the city and 6.5 L/100 km (36 mpg) on the highway.) Not only is that the best in class by a good margin, but it's the most fuel-efficient car BMW has ever sold in the United States.

Fortunately, the 5 Series car wrapped around this underdog engine is just as worthy. The 5 benefits from a handsomely understated design and such BMW niceties as the Driving Dynamics Control system. It lets drivers adjust controls over four settings to control throttle response, steering weight, transmission shift points, and with optional Sport packages, the firmness of the adaptive suspension.

At US $47 575 to start, the 528i costs about $2100 more than last year's six-cylinder model. At BMW, the power lunch is never free. ❑

THE ENGINE'S THE THING: **The BMW 528i is just one of the models that carry this type of engine.**

DOK-ING XD

A Croatian EV with up to four motors, the better to steer with

AUTO BUFFS HAVE ALWAYS loved an oddball, from the three-wheeled 1948 Davis Divan to today's frog-faced Nissan Juke and Scion's Mola-like iQ. Now comes the Dok-Ing XD, a three-seat charmer from Zagreb, Croatia. It's the quirkiest entry on our list, but it shows how the advent of electric drive is fueling the dreams and schemes of feisty entrepreneurs around the world.

The XD sprang from the personal vision of Vjekoslav Majetic, a mechanical engineer whose company builds remote-controlled vehicles to clear land mines, fight fires, and mine underground. Majetic hired a Croatian industrial designer to create an urban electric, then guided the designer's hand like a client ordering a bespoke suit.

The resulting car is petite and pod-like, at just under 3 meters long, but powerful and deluxe, with an adorable shape and gull-wing doors that captured everyone's attention at the most recent Los Angeles Auto Show.

The unusual passenger layout recalls the US $1 million McLaren F1 supercar, albeit in puny and electrified form: To maximize space and safety, Majetic's machine places the driver front and center, with two passengers comfortably stretched out behind and on either side.

With its 32-kilowatt-hour batteries packaged below the floor, the XD offers more cargo space than a similarly tiny, rear-engined Smart Fortwo. Dok-Ing says it chose the lithium-ion batteries to link to either two or four 45-kilowatt (60-horsepower) electric motors, with a choice of front-, rear-, or all-wheel-drive layout. With all four motors churning the wheels, Dok-Ing claims a ripping 4.2-second run from 0 to 100 kilometers per hour (0 to 62 miles per hour) and a driving range of about 250 kilometers on a charge. And as with some new electric sports cars, the XD's system allows torque vectoring, with the ability to speed or slow individual wheels to boost handling and stability.

The company hopes to build 100 cars this year, priced at around US $80 000, and to deliver its first customer cars in the third quarter of this year. It intends to ramp up production in 2013, with a target of 1000 cars a year, initially for European buyers. The company is eyeing a presence in the United States as well.

POWER PLANT: **Up to four electric motors totaling 180 kW (240 hp)**
BASE PRICE: **US $80 000 (estimate)**

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VOLKSWAGEN PASSAT

The smell of diesel in the morning

WHEN AMERICAN DRIVERS get giddy over diesel, eyes must roll in Europe, where diesel fuel powers nearly half the new cars sold.

But diesel cars are only starting to catch on now in the United States, and no company has seized the opportunity like Volkswagen. With a range of affordable choices, one in five VWs sold in the United States in 2011 was a diesel. And the new Passat TDI—a roomy family sedan, made in VW's new US $1 billion factory in Tennessee—seems certain to make more diesel converts.

Consider the fuel economy: 4.7 liters per 100 kilometers (50 miles per gallon). That's what I got, anyway, on a long highway run averaging 97 kilometers per hour (60 miles per hour). Even at higher speeds, the Passat returned a healthy 5.2 L/100 km (45 mpg).

That economy makes the diesel the smart-money choice. The TDI starts at $26 675, about $2200 more than the gasoline five-cylinder and roughly $1000 less than the V-6. But the diesel owner will save big at the pump. According to Environmental Protection Agency figures, the TDI diesel's annual fuel cost will be roughly $1800 a year, $600 less than the V-6 model's and $250 below the five-cylinder's.

ENGINE: 2.0-L turbo diesel, 104 kW (140 hp)
BASE PRICE: US $26 675

In diesel style, the VW's 2.0-liter turbo diesel gives you modest power but oodles of torque: 104 kilowatts (140 horsepower) and a fat 320 newton meters (236 foot-pounds) of torque. The upshot is robust passing power that belies the humble 8.6-second time it takes to get from 0 to 97 km/h.

Because high-compression diesels burn lean, using more air relative to fuel than gasoline engines do, they tend to produce high levels of smog-forming nitrogen oxides. To control them, the system takes urea, an ammonia-based catalyst, from an 18-liter tank and feeds it precisely into the exhaust stream, where it converts the oxides into harmless nitrogen and water.

The Passat's weak link, in my mind, is the too-safe styling, which recalls a cookie-cutter rental sedan. Yet this Passat has acres of useful space and has retained its signature German handling. It feels more expensive than it is.

And in contrast to many lifeless hybrids—the Toyota Prius comes to mind—this midsize VW diesel is roomier, more comfortable, and far more enjoyable to drive. Add it up, and the Passat TDI writes a compelling coming-to-America story.

Ford Focus ELECTRIC

An all-electric, with a charger that's fast on the draw

AMONG SEMIAFFORDABLE electric cars, the technology race is wide open. But in the design battle at least, Ford has an edge.

The Ford Focus Electric, with its appealing, Euro-hatchback lines, lacks the frumpy feel of self-denial often associated with electric cars. Maybe it's the finely ribbed grille, seemingly cribbed from Ford's former Aston Martin subsidiary. The first pure EV from a major Detroit manufacturer since GM's star-crossed EV1, the Focus relies on the

2012 FORD FOCUS ELECTRIC
POWER PLANT: Electric motor, 107 kW (143 hp)
BASE PRICE: US $39 995

ultimate cleaner-than-thou argument: zero tailpipe emissions. (Recharging it, of course, leaves a carbon footprint, unless you have a wind turbine in your backyard.) It also plays on consumer familiarity: Unlike the Nissan Leaf or Chevy Volt, the Focus is an electrified version of an existing gasoline model.

The Focus's front wheels are driven by a 107-kilowatt electric motor (143 horsepower), with 250 newton meters (184 foot-pounds) of torque. That muscle is countered, however, by chubbiness at the curb, with the Focus's 23-kilowatt-hour, lithium-ion battery the chief culprit: This EV weighs 1666 kilograms (3673 pounds)—329 kg more than the gas-powered hatch.

The big technical trump card is the 6.6-kW onboard charger, which allows the Focus to charge in about 3.5 hours, half the time the Leaf's 3.3-kW unit requires.

Yet the Focus stumbles in trunk space, which is hogged by a portion of the battery pack. Both the Leaf and Volt managed to sandwich *their* battery packs entirely below the floor. Like the Volt, the Focus surrounds its battery pack and electronics with liquid cooling; Nissan chose to go with an air-cooled design.

The U.S. Environmental Protection Agency pegs the Focus's fuel economy at 2.2 liters per 100 kilometers (105 miles per gallon) and its driving range at 122 kilometers (76 miles), topping the Leaf's 117 km. Of course, range varies with temperature; frigid weather can chop 20 percent from an EV's real-world range.

The Focus lacks the Volt's gas engine and indefinite range, but that fact hasn't deterred Ford from pricing the Focus almost identically to the Volt, at US $39 995. Even if you throw in the $7500 U.S. government tax credit, the Focus Electric will still cost about $8000 more than a comparably equipped gasoline version. The Focus is now on sale, but only in limited U.S. markets, including New York, New Jersey, and California. ❑

CURRENTLY FILLING UP: The Focus charges in just 3.5 hours, then a push of a button gets it going.

Ferrari FF

Sweet excess—12 cylinders, 651 horses, and four-wheel drive

RUSSIAN OLIGARCHS and New Jersey housewives lusted equally after the Porsche Cayenne SUV. And then came four-door Aston Martins, and soon there'll be a Maserati SUV, built in Detroit on the bones of a Jeep Grand Cherokee.

This is what happens when even the wealthy start making room in their fantasy garages for "practical" cars.

But now here's Ferrari ratcheting up the blasphemy with—this is not a typo—what seems to be a station wagon. That kind of heresy might require the Vatican to get involved. So let's not call it that. Let's refer to it simply as a US $300 000, 335-kilometer-per-hour (208-mile-per-hour) snow bunny with room for four pampered adults.

At 485 kilowatts (651 horsepower), this is the most powerful Ferrari road car yet and the only one to have all-wheel drive. To demonstrate its practicality, the company last year borrowed Chinook helicopters from the Italian Army, stuffed FFs inside them, and carted a small group of auto writers up a peak in the Dolomites to speed around a snow course in front of gaping skiers. Yet the Ferrari doesn't need winter weather to send chills down your spine. In any road condition, the FF—which stands for Ferrari Four—feels both safe and sensational.

The technical revolution here lies in the way Ferrari overcame the compromises of all-wheel drive, including the added mass and unbalanced, nose-heavy handling. The Mediterranean magic begins with a weight-saving aluminum space frame, which has 23 separate alloys in its many extrusions and castings. Below the FF's insanely stretched hood, a new 6.0-liter V-12 is mounted entirely behind the front axle, for better weight distribution. A high 12.3:1 compression ratio helps the engine scale the revolution-per-minute heights to 8000. The 97-km/h (60-mph) barrier falls in 3.7 seconds.

Ferrari's latest seven-speed, dual-clutch F1 gearbox sits at the rear, melded to several other Formula One–derived systems. They include an electronic rear differential, or E-Diff, which works with the F1 Trac traction control to analyze available grip among the tires in real time, divvy power between the rear wheels, and generally abuse the pavement.

A magnetorheological suspension uses a magnetic field to instantly vary the viscosity of the metal-particle-infused fluid in its shock absorbers. The unit senses the road surface and *g* forces on the car and can adjust suspension firmness every millisecond.

As ever, the *manettino* is the Ferrari's mission control center, the tiny red lever on the steering wheel that adjusts the engine, suspension, transmission, throttle, and stability systems. But for the FF, the manettino has a new playmate—the company's unprecedented design for all-wheel drive.

The main handling challenge of all-wheel drive is the unwieldy bias of the weight of the car toward the front wheels. To counter this bias, Ferrari used a drive-by-wire system. There's no weighty secondary driveshaft, no center differential between the front and rear axles. Instead, the Ferrari's longitudinally mounted engine sends power aft via its Power Transfer Unit (PTU), which is just 6.7 inches long and less than 41 kilograms (90 pounds). The mechanical sleight of hand results in a Ferrari with a 47/53 percent weight distribution from the front to the rear.

You may well wonder about the design of the world's first car with one transmission for the front wheels and another for the rear ones. The system actually strives to send all its power rearward, as God and Enzo Ferrari intended, but only up until its predictive algorithms decide that traction or stability is in jeopardy.

When that happens, on wet pavement or dry, the front wheels become your trusty wingman: The PTU draws up to 20 percent of the power through a pair of wet, carbon-fiber-lined clutches, vectoring torque to either front wheel. If rear tires should break loose from the pavement in the main transmission's first gear or second gear, the front transmission's first

2012 FERRARI FF

ENGINE: 6.0-L V-12, 485 kW (651 hp)

BASE PRICE: US $300 000

gear feeds in power to help out. Lose traction in third or fourth gear—now we're talking speeds of roughly 185 km/h (115 mph) or higher—and the front wheels restore control via the PTU's second speed. Fire this Italian projectile into fifth, sixth, or seventh gear and the rear wheels can handle any added torque, so the front axle's clutches remain open and no power transfer takes place.

In the manettino's Snow/Ice setting, the Ferrari is as docile as a Toyota (albeit one with 651 hp) with systems prioritizing traction and safety over speed. When I attempt to unsettle the FF with lurid jabs of the throttle or jerks of the steering wheel, it simply ignores my clumsy commands and stays serenely planted.

Move up through the settings and the electronic leash is progressively loosened, allowing expert drivers to drift the FF like a rally racer. Throw in 20-inch Pirelli Sottozero winter tires and the FF will humiliate an Iditarod dog team.

And even on a dry road, as the Ferrari's own howl echoes through the Dolomites, the four-wheel system stays in the wings but remains ready for action: Exiting a corner in second gear, rolling hard onto the throttle, I hit some unexpected pebbles, and the Ferrari's rear end shimmies sideways. A dashboard light flickers, the front tires claw at the pavement, and I'm instantly back on line—no harm, no foul, and best of all, no plunge off the cliff.

On the fuel-sucking front, the Ferrari's optional HELE system (for High Emotion/Low Emissions) adds an engine stop-start system and a more efficient fuel pump and air-conditioning compressor. The result is a car that emits 360 grams of carbon dioxide per kilometer and can sneak past 15.7 liters per 100 kilometers (15 miles per gallon). That's hardly frugal, of course, but it's still 25 percent better than recent Ferrari V-12s, despite the 20 percent increase in horsepower.

For the ultrahigh-net-worth individuals who wait patiently for any new Ferrari, the FF might seem a strange proposition: When the weather turns nasty, why not grab the keys to the Range Rover instead?

Think Gucci loafers rather than Church's brogues and the Ferrari's purpose becomes clear. Range Rovers litter the landscape of any upscale suburb. But pull up to the valet in the Ferrari FF, skis strapped to the roof, and you've got the ultimate in winter one-upmanship from Vail to Gstaad. ❑

PORSCHE GT3 R HYBRID

Big flywheel, keep on turning

LABORATORIES ARE USUALLY pretty quiet places. Not so the Porsche GT3 R Hybrid. Electrified and electrifying, this 500-kilowatt (670-horsepower) track banshee heralds a new hybrid age in the top levels of racing. Porsche's rolling experimental race lab is spearheading the German automaker's return to the top prototype class at the 24 Hours of Le Mans in 2014, following a 16-year absence.

The Creamsicle-orange Porsche might appear to be its traditional GT fighter: There's the expected rear-mounted flat-six engine driving the rear wheels, here a 4.0-liter with variable valve timing and 350 kW (470 hp). But up front, this historic car is the first Porsche racer with electric front-wheel drive. What's more, the electricity comes not from a battery but rather a flywheel-driven energy recovery system.

In racing, these Kinetic Energy Recovery Systems, or KERS, were first introduced in Formula One racing in 2009, with rules allowing either electric (battery) or mechanical (flywheel) systems. Mechanical systems are more efficient, in part because the energy doesn't have to change its state as often.

ENGINE: 4.0-L flat-six, 350 kW (470 hp), plus 150-kW electric drive

PROTOTYPE; No price yet

The flywheel is composite, which means that a crash or system failure won't send metal fragments exploding through the cabin—a good idea for a 14-kilogram (31-pound) flywheel that revolves up to 600 times per second.

Inside the Porsche, that carbon-fiber-encased flywheel spins less than half a meter from the driver, whirling at ear-rending decibel levels. Pump the brakes and a pair of 75-kW motor-generators accelerate the flywheel, charging it to maximum capacity. Pushing the boost button on the steering wheel reverses the motors' function to that of generators, which squirt 150 kW (201 hp) to the front wheels. That electron-enabled boost lasts for up to 8 seconds, perfect for overtaking a slower—and perhaps entirely gasoline-driven—competitor.

The hybrid system does more than trim critical tenths of a second from lap times, it also conserves fuel. Competing unofficially at an American Le Mans Series event at California's Mazda Raceway Laguna Seca, the Porsche stopped just three times for fuel, compared with at least five stops for rivals—a key feature in races that can last up to 24 hours.

The maker of the flywheel, U.K.-based Williams Hybrid Power, is developing a fully composite flywheel for use in street cars.

GOOD NIGHT, MOON: A big enough chunk of junk from the solar system could kill most living things on Earth.
ILLUSTRATION: ALAMY

Deflecting Asteroids

A solar sail could use light to nudge an earthbound rock into an orbit we could live with \ By Gregory L. Matloff

SIXTY-FIVE MILLION YEARS AGO, a Manhattan-size meteorite traveling through space at about 11 kilometers per second punched through the sky before hitting the ground near what is now Mexico's Yucatán Peninsula. The energy released by the impact poured into the atmosphere, heating Earth's surface. Then the dust lofted by this impact blocked out the sun, bringing years of wintry conditions everywhere, wiping out many terrestrial species, including the nonfeathered dinosaurs. Birds and mammals thus owe their ascendancy to the intersection of two orbits: that of Earth and that of a devastating visitor from deep space.

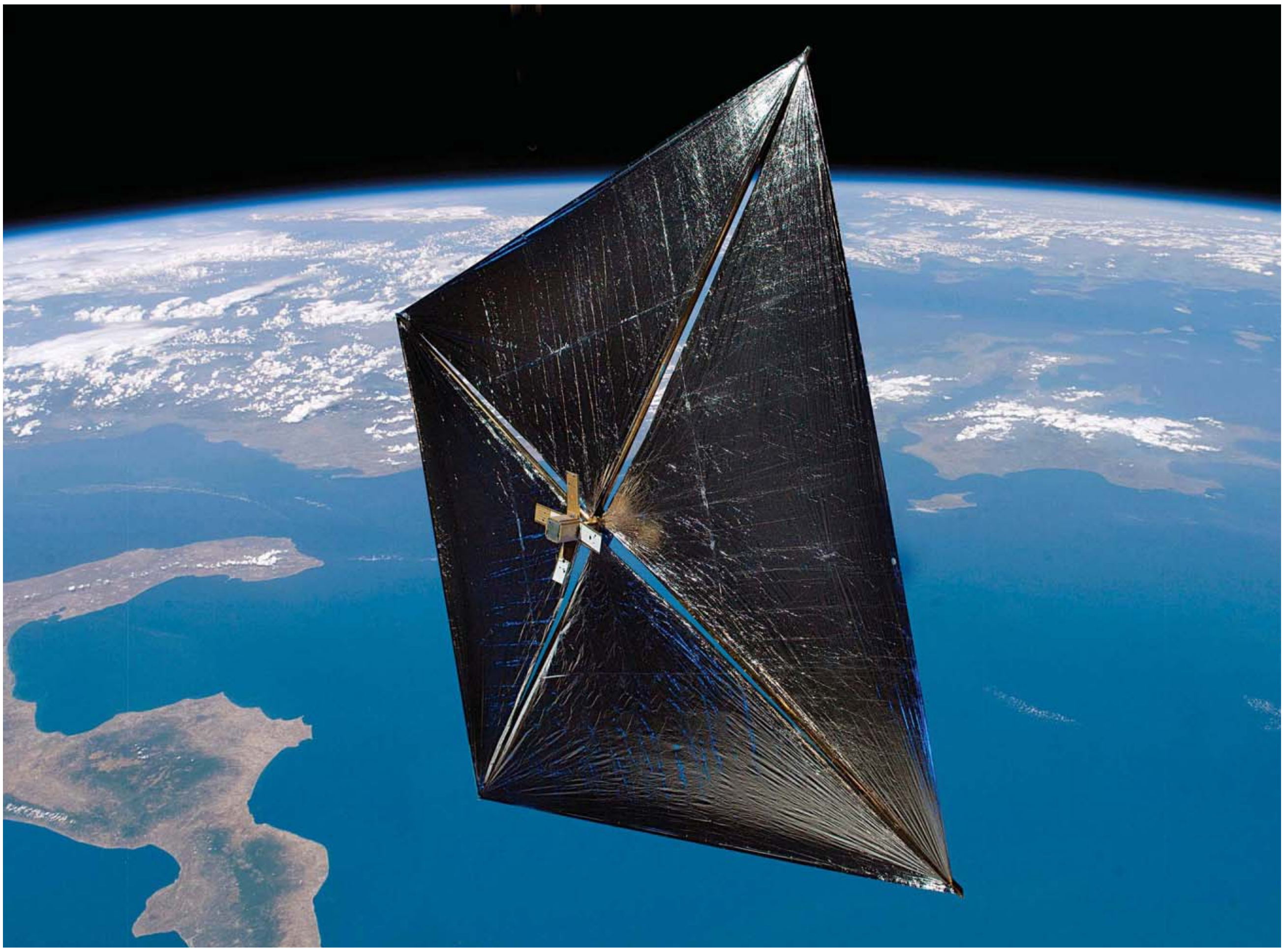
We humans need not wait, like dinosaurs, for the next big rock to drop. We have an advanced understanding of the heavens and a spacefaring technology that could soon enable us to alter the orbits of any celestial object on a collision path with us. That capability just might come in handy.

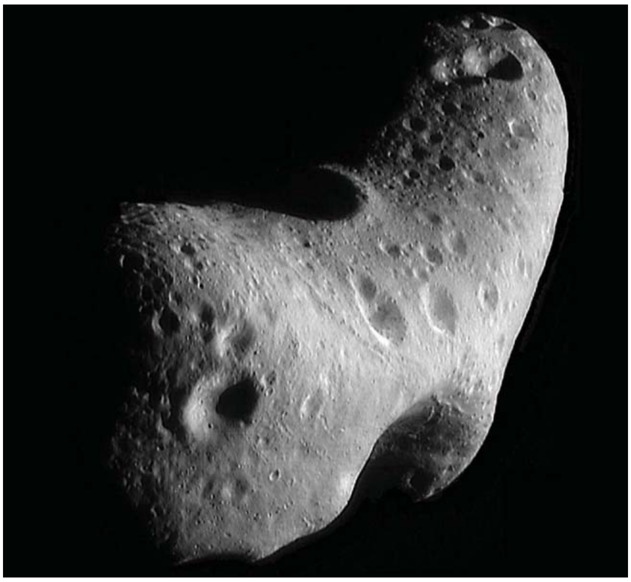
We got a taste of the challenge in December 2004, when scientists at NASA and the Jet Propulsion Laboratory (JPL), in Pasadena, Calif., estimated there was a nearly 3 percent chance that a 30-billion-kilogram rock called 99942 Apophis would slam into Earth in 2029, releasing the energy equivalent of 500 million tons of TNT. That's enough to level small countries or raise tsunamis that could wash away coastal cities on several continents. More recent calculations have lowered the odds of a 2029 impact to about 1 in 250 000. This time around, Apophis will probably miss us—but only by 30 000 km, less than one-tenth of the distance to the moon.

But let's not rejoice too quickly. We know next to nothing about that asteroid's porosity, composition, and tensile strength. It's possible that tidal stresses during its 2029 approach could cause it to break apart, adding to the odds of an Earth impact during another rendezvous further down the line.

There is some disagreement about the best course of action. In the United States, experts tend to want to experiment with various deflection techniques by first sending robots or even astronauts to asteroids that do not threaten Earth. But in Russia, many asteroid watchers believe the risk of a collision between Apophis and Earth has been underestimated. These analysts contend that we should therefore concentrate our experiments on this particular asteroid.

To be sure of diverting any interplanetary intruder, we would need several strings to our bow. A method that could swiftly deflect a hunk of iron might blow an icy rock into several parts, each of which could then become a danger. And the gentler method now being discussed—to vaporize part of the surface of the asteroid, creating an outpouring of gas that would generate a propulsive force—would do no more than warm a





ASTEROID EROS: The first space rock observed from close quarters [left] is itself a potential threat to Earth. A solar sail [artist's conception, above] might focus light onto such an object, heating ice into water vapor that would serve as a propulsive jet.

IMAGES: JPL/NASA

meteorite made of iron. So we'll doubtless need to devise several strategies for dealing with threatening asteroids.

So I have proposed a new tool, one that would use the pressure of light to nudge threatening objects into safe trajectories. That I've been asked to explain it at all in a magazine article shows that there's indeed one thing we can rejoice in: the enhanced awareness of the problem. The mention of killer asteroids no longer raises jeering comparisons to the cries of Chicken Little, now that we know celestial impacts are far more common than once thought.

The largest and most famous Earth impact in historical times occurred in Tunguska, Siberia, in 1908, when an object perhaps 30 meters wide entered the atmosphere and exploded aboveground, with the strength of several megatons of high explosive. It leveled forests and dispersed reindeer herds, and the dust it kicked up produced colorful sunrises and sunsets throughout Europe. Fortunately, the devastated area was sparsely populated, so few people were hurt.

Astronomers now know a good deal about the nature and location of objects posing threats of both the Yucatán and Tunguska kinds. Some of these objects are comets—celestial icebergs that spend most of their time in the depths of space far from the planets. At intervals of 100 000 years or more, stars may approach our solar system closely enough to disrupt the solar orbits of some of these comets, pushing them sunward. They would then swoop through the inner solar system at great speed. It is not impossible that such a comet is what destroyed the dinosaurs.

The main threat comes from what are known as near-Earth objects. They usually reside between the orbits of Venus and Mars, although their orbits aren't very stable. Most are eventually flung out of the solar system, but replacements wandering in from the main asteroid belt maintain their population. Some 7000 near-Earth objects have been identified so far. As many as 100 000 more, all larger than the Tunguska object, may await discovery. This guesstimate, by analysts at JPL, is based on the assumption that astronomers are far better at spotting mountains than molehills.

NASA, now joined by the European Space Agency and other space agencies, has been conducting systematic searches for these objects. The agencies hope that by 2020 they will be able to discover 90 percent of those near-Earth objects wider than 140 meters. Both terrestrial and space telescopes are involved in the effort, and amateur astronomers equipped with small, dedicated telescopes also contribute.

Most of our information on the physical properties of these objects comes from low-resolution radar images created using such devices as the 300-meter William E. Gordon Telescope at the Arecibo Observatory, in Puerto Rico. This radio telescope can reveal rotation rates and shapes, at least for the nearer objects, although there is much we must still learn. What we do know, from meteorite samples in museum collections, is that some of the interplanetary objects that strike Earth are metallic, consisting largely of iron, and that some are rocky, consisting largely of silicates. Then there are extinct comet nuclei, in which rocky layers are interleaved with volatile material—ice made of water or methane, for example.

An additional asteroid category has recently been added to the list. The Japanese space probe Hayabusa (formerly called Muse-C) arrived at asteroid Itokawa in September 2005. In a cliffhanger of a mission, the probe landed on the asteroid and retrieved samples of the surface, returning with them to Earth in June 2010.

In early 2007, I took part in a NASA Marshall Space Flight Center study of proposed deflection techniques that could be ready for use by the end of 2020. My colleagues and I assumed that by that point we'd have a heavy-lift booster capable of sending 50 000 kg or more on an Earth-escape trajectory.

We considered several strategies. The most dramatic—and the favorite of Hollywood special-effects experts—is the nuclear option. Just load up the rocket with a bunch of thermonuclear bombs, aim carefully, and light the fuse when the spacecraft approaches the target. What could be simpler? The blast would blow off enough material to alter the trajectory of the body, nudging it into an orbit that wouldn't intersect Earth.

But what if the target is brittle? The object might then fragment, and instead of one large body targeting Earth, there could be several rocks—now highly radioactive—headed our way. Also, a lot of people might object to even the mere testing of any plan that involved lobbing 100-megaton bombs into space. The nuclear option might then be limited to a last-ditch defense of Earth, should we get little warning of an impending impact.

Another idea is to use the "kinetic" method, which essentially uses one bullet to hit another. It requires sending a small spacecraft into an orbit around the sun in the opposite direction of that of the planets and most other objects. You then maneuver this spacecraft to hit the target head-on. It would take months to accelerate something into such a retrograde orbit. Still, the job could be done using either a solar-electric (ion) engine or a

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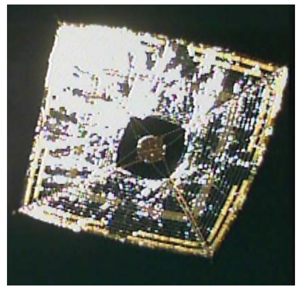
solar sail, which would use the tiny pressure that sunlight exerts on it to maneuver through space. A craft that hit the Earth-threatening rock with a relative velocity of about 60 km/s would impart a kinetic energy of 1.8 billion joules per kilogram. If the aim was perfect (no small feat at such a relative velocity), the collision could significantly alter the orbit of an asteroid—one that's sturdy enough to take the impact without falling apart. Of course, the thing could fragment, which might just make things worse.

But if we had several decades to plan the intervention, we could apply force more gently and with better control. We could wrap a solar sail around the offending object, like aluminum foil around a potato, changing the degree to which it reflects light and thus the effective pressure that sunlight exerts on it. In this fashion, the sail could gradually alter the object's orbit around the sun, converting an impending Earth impact into a near miss. This wrapping method ought to work for any kind of asteroid or comet.

Apollo 9 astronaut Rusty Schweickart and Bong Wie of Iowa State University have proposed yet another universally applicable solar-sail technique, called the gravity tractor. Here a solar sail would maintain position near the threatening body for decades, exerting a small but significant gravitational attraction on that object, which over time would alter its course. The sail would move into position and remain there using the pressure of solar radiation to maneuver. This method has the advantage of working equally well on all classes of objects—metallic, stony, or rich in ice. It would take a very long time, however, to do the job.



VENUS, HO: In late 2010, Japan's IKAROS became the first spacecraft to use a solar sail for interplanetary travel. *PHOTO: JAXA SPACE AGENCY*

For the 2007 NASA Marshall study I began working on yet another scheme, called the solar collector. H. Jay Melosh of the University of Arizona and Ivan V. Nemchinov and Yu. I. Zetzer, both then affiliated with the Russian Academy of Sciences, first proposed this approach in 1994. For this strategy, the spacecraft would deploy a large parabolic reflector that would always face the sun. Although the reflector would resemble a typical solar sail, its purpose would be solely to concentrate sunlight onto a smaller flat mirror, known as a thruster sail. The thruster sail would direct concentrated sunlight onto the offending asteroid. If the object contained volatile material, the intense beam would heat things up enough to vaporize part of the surface. The gas shooting into space as a result would, over time, impart enough momentum to nudge the body's solar trajectory away from a projected impact with Earth. It wouldn't take much of a push, because with asteroids, unlike horseshoes, a near miss doesn't count.

The version of this approach that I worked on for the NASA Marshall study in 2007 assumed that gas would shoot off the asteroid at a velocity of about 1 km/s. This estimate drew on an experiment Melosh and his colleagues had done long before, using a pulsed laser to heat a simulated chunk of rocky intrasolar debris. But I had some suspicions that this number was too high—that it overestimated the efficiency of this approach. So I later looked into the thermodynamics of the problem more closely.

As I described in a 2008 paper in *Acta Astronautica*, it turns out that much of the energy in the concentrated beam of light would simply get conducted through the rock, away from the hot spot. The beam would have to be quite powerful to ensure that the hot spot could evaporate enough volatile material to really do the job. I found that what really mattered was how deep the concentrated sunlight penetrates. Existing studies showed that most soils here on Earth allow light into just the top 100 micrometers, but measurements on extraterrestrial samples were lacking.

As an associate at the Hayden Planetarium at the American Museum of Natural History, in New York City, I was able to collaborate with Denton Ebel, curator of meteorites there. He graciously prepared two samples of the Allende meteorite, which slammed into Mexico back in 1969. It's a carbonaceous chondrite, as are about a third of all near-Earth objects. The first sample consisted of a 30-µm-thick section epoxied to a transparent slide; the second was a finely ground simulated minimeteorite weighing just a few grams.

Both samples were loaned to the physics department at the New York City College of Technology, in Brooklyn, where I teach. There, Lufeng Leng and her student Thinh Le shone two laser beams onto the samples, one at a wavelength of 532 nanometers, in the green part of the spectrum, and the other at 650 nm, in the red part. It turned out that both samples had about the same light-penetration depths you'd expect to find in terrestrial soils. I presented those results at a meeting of the Meteoritical Society in July 2010.

Such measurements must be repeated at other wavelengths and on samples of other meteorites and, ultimately, on samples retrieved from the moon and from asteroids. That way we will be able to test extraterrestrial material that could not have been modified by a meteorite's white-hot passage through Earth's atmosphere.

At this stage of the analysis, it is difficult to determine how big a solar collector would be required for this strategy to work. The device would probably have to measure more than 50 meters. Building it from a thin plastic film would keep its mass down to no more than a few hundred kilograms. It would remain tightly folded on the voyage out and be unfurled only near the standoff point, at least a few hundred meters from the Earth-threatening rock. Electric propulsion would probably be necessary to maintain the collector's position during the months or years it would take to divert the rock. Autonomous robotic control seems necessary, although astronauts could certainly monitor the process. And it might prove easier to use a number of smaller solar collectors rather than a single large one.

These are early days for designing such delicate space hardware, space sails included. But that solar sails can be manipulated in orbit and used for various purposes is no longer in doubt.

In 2010, two such sails flew in space. The more ambitious one, a square about 14 meters on a side, was launched by the Japanese space agency on an interplanetary trajectory between Earth and Venus. Called IKAROS, for Interplanetary Kite-craft Accelerated by Radiation Of the Sun, it proved that solar radiation pressure can be used both for primary propulsion and for attitude control. A follow-on craft, planned for around 2020, would use its solar sail during a close pass of the sun. There it could gain enough momentum from light pressure to swing into an orbit that would take it all the way out to explore the asteroids—called the Trojans—that trail Jupiter in its orbit.

NASA's Nanosail-D2, approximately the same size as IKAROS but lighter, went up in late 2010 and deployed in January 2011, when the craft unfurled its sail in an Earth orbit low enough for amateur astronomers to see it. It was also low enough for atmospheric drag to affect the orbit. In this case, that was a feature, not a bug, because the point of the mission was to clean up space junk by docking with it and then using the sail to drag it down to a fiery disposal in the lower atmosphere.

It's a good thing that solar sails have many possible uses. This helps to defray the costs of developing a technology that's likely to be valuable should we ever discover a rogue asteroid headed our way. It also helps in overcoming the all-too-human reluctance to begin working on a problem that requires a planning horizon measured in generations or even centuries.

As with other approaches to asteroid deflection, the solar collector would not work well on all classes of interplanetary rock. If you tried to use it on an iron asteroid, the metal would instantly conduct the heat away from the hot spot. Besides, there would be no volatile material there to vaporize anyway. The asteroid would just continue on its merry way, undisturbed. A rocky body without any volatiles would also be impossible to shift in this way. So, clearly, other techniques for dealing with those kinds of asteroids must also be developed.

It does seem, though, that a solar collector could divert a 300-meter water-ice object enough to prevent an Earth impact, and while remaining on station for just a few months. Even more ambitious is the notion of using such deflection techniques to steer smaller water-ice-bearing objects into high Earth orbit, where we could mine them for materials for rocket fuel, life-support systems for space habitats, cosmic-ray shielding for such habitats, the construction of satellites to beam solar power to Earth, and other purposes. In 2010, President Obama directed NASA to prepare to send astronauts to explore near-Earth objects by the year 2025. While on that mission or on succeeding ones, astronauts could test a solar collector and other deflection techniques.

We have plenty of time to study the matter. But we do not have all the time in the world. ❑

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Rolls-Royce

Professorship in Power Electronics

The **Nanyang Technological University** (NTU), an internationally renowned tertiary education institution located in Singapore, is seeking a world renowned **Professor of Power Electronics** for its **School of Electrical and Electronic Engineering** (EEE). This appointment will be supported by **Rolls-Royce plc** to develop power electronics technologies for various business sectors.

A fast-rising global university, NTU has been consistently ranked among the world's top 1% of universities. In 2011, NTU jumped 16 places in the QS World University Rankings to 58th position, making it the Asian university with the biggest leap in the Top 100. Its School of Electrical and Electronic Engineering is renowned for its high academic standards and strong tradition in research. To support teaching and cutting-edge research, this school is host to 9 mega research centres and more than 50 laboratories, which are well-equipped with modern facilities and state-of-the-art equipment.

Rolls-Royce plc is a world-leading provider of power systems and services for use on land, at sea and in the air. It has a balanced business portfolio with leading positions in the civil and defence aerospace, marine and energy markets. Its global Electrical Power and Control Systems (EPACS) group is supporting the increased electrical requirements from the business through technology development and acquisition.

The ideal candidate is expected to possess an international reputation as a technological leader in this field and a record of distinguished academic and scholarly achievements, along with a demonstrated commitment to the core traditions of excellence and innovation. As a tenured full professor, he/she is also expected to provide academic leadership and excellence in the area of power electronics for the School of EEE of NTU.

The selected candidate will be expected to work closely with Rolls-Royce in developing capability aligned with the technology needs of the company in the area of power electronics and the use of power electronics in power systems.

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Chairman, School Search Committee
c/o Head of Division of Power Engineering
Email: eeehr@ntu.edu.sg

Please ensure that your CV, among other information, also includes the following.

1. a detailed teaching plan and research plan
2. number of and monetary amount of research grants held at present and in the past
3. number of Masters and/or PhD students currently supervising/co-supervising
4. number of Masters and/or PhD students graduated
5. Referees - provide the names, addresses, email addresses and fax numbers of 5 referees

Electronic submission of applications is encouraged. Only short-listed candidates will be notified.

Application Deadline: Position opens until filled

國立交通大學 National Chiao Tung University 台南分部 光電學院

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For more information, see http://www.nctu.edu.tw/ and http://www.cop.nctu.edu.tw/.

Interested applicants should send a cover letter, curriculum vitae, copies of representative publications, photocopy of diploma, research summary and teaching portfolio, and an application form (**http://www.cop.nctu.edu.tw**) and arrange 3 letters of recommendation sent to Faculty Recruitment Committee, College of Photonics, National Chiao Tung University, Tainan Campus (No.301, Gaofa 3rd Rd., Guiren Dist., Tainan City 711, Taiwan (R.O.C.)) before **Apr. 20th, 2012**.

Contact: **chialing@nctu.edu.tw.**, Ms. Lin

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Please send the nomination or application enclosing a current C.V. with evidence of teaching ability in English and a concise (up to one page) statement of research interests and teaching philosophy to the Human Resources Office. **Applications will receive full consideration until the positions are filled.** Please quote the reference of the post in the application and on the envelope. The University reserves the right not to fill the positions. Personal data provided by applicants will be used strictly in accordance with the University's personal data policy, a copy of which will be provided upon request.

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Please submit applications with the usual attachments and three referee names, quoting the reference number, to the Head of the Department of Electrical Engineering and Information Technology, Technische Universität Darmstadt, Merckstrasse 25, D-64283 Darmstadt, Germany, E-Mail dekanat@etit.tu-darmstadt.de.
For further information please contact the Chair of the Search Committee, Prof. Dr.-Ing. Hans Eveking, Tel.: 06151/16-2076, E-Mail: eveking@rs.tu-darmstadt.de.

Application deadline: 31-May-2012

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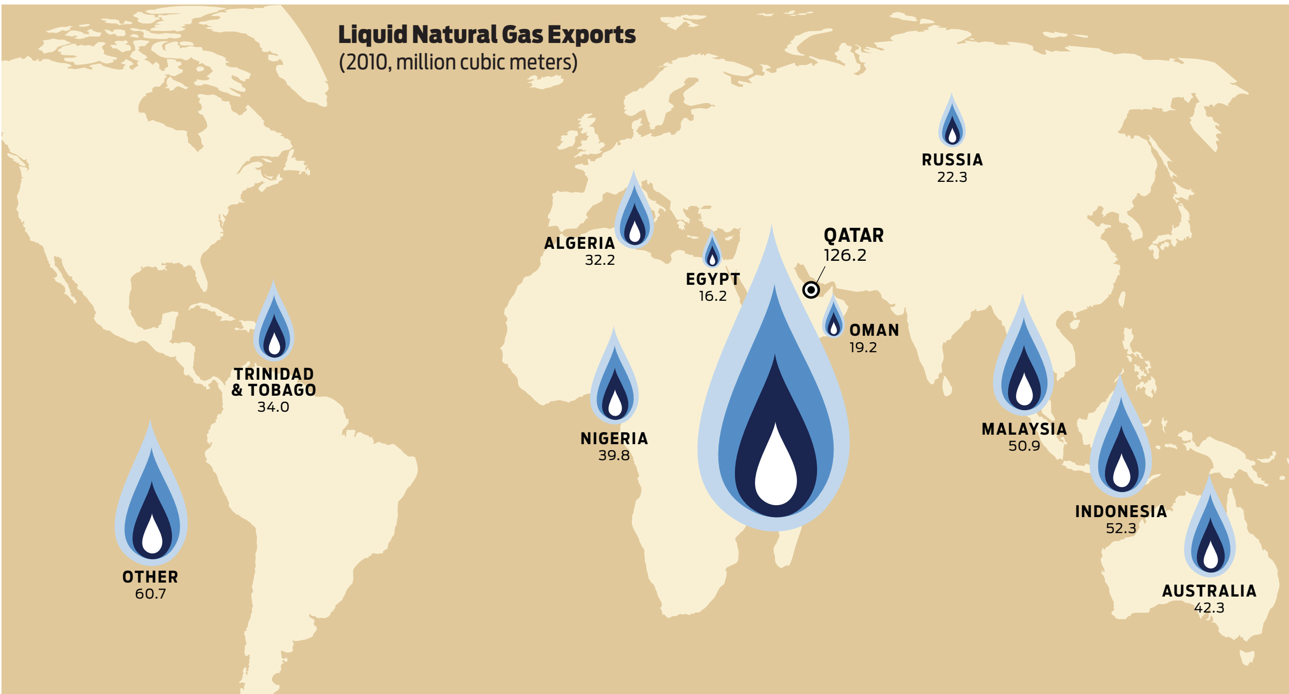


LNG Rising

Exporters have been shipping liquefied natural gas (LNG) since the first specialty carrier—the MV *Methane Princess*—was built in 1964.

But although LNG is twice as dense as compressed pipeline gas, the high costs of first cooling the gas to –162 °C to liquefy it for shipment and then regasifying it at the import terminal kept the market tiny for three decades.

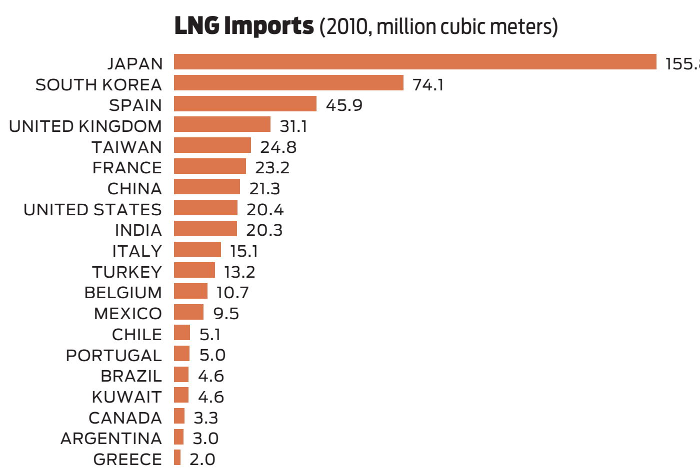
Then, in the late 1980s and 1990s, a confluence of factors opened the market up: Gas-fired power plants became popular, owners of oil fields became more interested in the extra income natural gas offered, and the terms of LNG trade contracts shifted from cumbersome 20-year arrangements to short-term sales agreements.

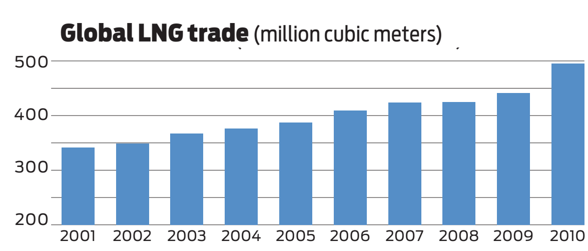
Since 2001, the total volume of LNG shipped has doubled to reach 496 million cubic meters, the energy equivalent of about one and a half billion barrels of oil. Between 2009 and 2010 alone, world trade grew by 22.6 percent.

Qatar single-handedly exports about a quarter of the world's LNG—all of which travels through the recently troubled Strait of Hormuz. The country harvests its supply from the South Pars/North Dome gas field, the largest in the world, which it co-owns with Iran.

On the receiving end, Japan is responsible for nearly a third of total imports. Gas-fired power has risen so sharply that it recently edged out oil-fired generation in terms of megawatts of electricity produced. Post-Kyoto and post-Fukushima, that trend will surely continue.

—Ritchie S. King





Sources: *BP Statistical Review of World Energy, June 2011*; Jensen Associates

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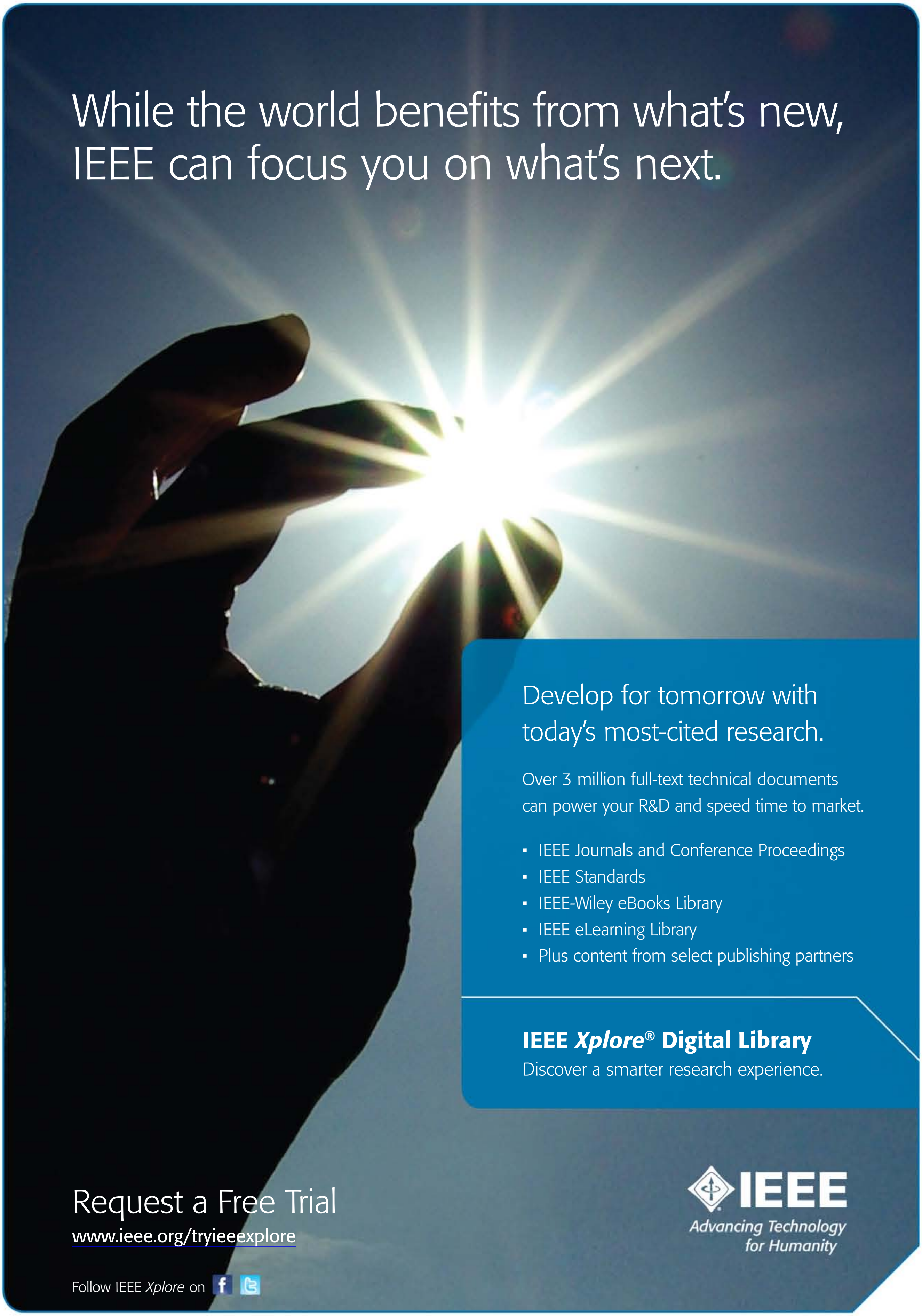
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